VIEW OF PORTION OF NEW YORK STATE AGRICULTURAL EXPERIMENT STATION AT GENEVA

Fertilizers and Crops

Or

The Science and Practice of Plant-Feeding

A Presentation of Facts, Giving Practical Methods for Using Fertilizers in Crop Growing, with Special Emphasis on the Reasons Underlying Their Use, and on the Conditions of Their Greatest Efficiency

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ILLUSTRATED

NEW YORK

ORANGE JUDD COMPANY

LONDON

KEGAN PAUL, TRENCH, TRÜBNER & Co., Limited

1919

PRINTED IN U. S. A.

PREFACE

During the past generation there has been intense and ever increasing activity among agricultural investigators in the study of problems relating to plant nutrition and soil fertility, covering all the various phases, chemical, physical and biological. Much work has been done in making practical application of the results of investigation to the use of plant-foods in the growing of crops. As an outgrowth of this activity, numerous books relating to soils, crop growing, fertilizers and kindred subjects have appeared, some treating certain limited aspects in much detail, others discussing all phases in a general way. For some time, however, there has existed marked evidence of a growing demand for a book which should not only assemble in a connected way the more important facts and principles relating to soil fertility and plant nutrition, but which should follow such a preparatory foundation with a systematic, reasonably thorough study of plant-foods in relation to practical use in crop growing. In the attempt to meet such a demand, this book has been prepared. Effort has been made to keep in mind the needs not only of students in agricultural schools but, even more, of the larger class of student farmers who are directly and vitally interested in the profitable production of crops.

It has seemed not only desirable, but essential, that a book treating of the practical use of fertilizers on the farm should be something more than a mere collection of recipes giving the number of pounds of different fertilizing materials to apply for individual crops; there should, in addition, be made as prominent as possible other vital factors influencing or controlling the effectiveness with which a crop utilizes the plant-food furnished

it. The purpose has been, therefore, not merely to give information but to present it in such a systematic way as to show certain fundamental relations and make clear, as far as possible, the reasons underlying every practice suggested. When the subject is considered in this broad way, it is obviously practicable to give only the most important details; and, therefore, in the preparation of many of the chapters, especially in the first part, the purpose has been to make the treatment, however incomplete, yet sufficiently full and suggestive to stimulate a desire on the part of the reader to know more about the subjects discussed, the information imparted thus serving as an introduction to further study of special treatises on agricultural chemistry, soil physics, plant physiology, soil bacteriology, etc.

It has been the privilege of the writer for nearly a quarter of a century to be in more or less constant touch with plant-feeding questions. Through personal contact he has been enabled to learn the practices, difficulties and needs of the farmer in relation to many problems of crop-feeding. To no small extent, this book is, therefore, the outgrowth of an appreciation of the farmer's point of view, and it seeks to arrange for his use many of the facts and principles he wants and needs to know.

In addition to the preceding statements, there are certain other points to which we wish to call attention briefly, relating to (1) sources of material, (2) new facts and theories, (3) definitions, (4) nomenclature, (5) illustrations and (6) use of the book.

(1) Sources of material. In addition to the extensive literature furnished by the investigations of our American agricultural experiment stations and colleges, and of the United States Department of Agriculture (especially the Bureaus of Soils, of Plant Industry, and of Chemistry), the results of work done at European agricultural experiment stations have been studied. Standard works of

specialists have also been freely consulted, among which may be mentioned those of Johnson, Storer, Hilgard, Voorhees, Wiley, Hall, Hopkins, King, Lipman, Lyon and Fippin, Bailey, and Hunt. It is obvious that the comprehensive, elementary character of the book makes it impracticable to give authorities and references for the statements made.

(2) New facts and theories. Not a month passes which fails to bring some new fact of interest, if not of importance, relating to one or more of the subjects considered in this book; such is the fruitfulness of the activity of investigation in these lines. While many facts and their interpretation must be regarded as satisfactorily established, there are many statements which will need modification as the result of increased knowledge. The present appears to be pre-eminently a time of flux and transition. Especially is this true in regard to theories of soil fertility and soil infertility. A theory is simply a proposed explanation of an observed fact or set of facts. Theories usually change with the accumulation of new facts. The discussion of theories has been purposely minimized by the writer, nothing more being attempted than here and there a brief statement without controversial discussion.

In any elementary treatise largely concerned with practical applications, one is often compelled, for the sake of brevity and directness, to make unqualified, positive statements, which are known to be only approximations to the truth, but which are sufficiently accurate for all practical purposes.

(3) Definitions. A satisfactory definition is usually difficult to make, and yet in any discussion it is essential to define fundamentals in order to avoid misunderstanding. In the literature relating to soils, plant-foods, etc., not a few terms, such, for example, as plant-food, soil fertility, and availability of plant-food, are used so loosely

by different writers as to have quite variable signification. Many of the definitions attempted in this book are open to criticism, as the author appreciates, and yet it is desirable that terms be defined, even if not with complete satisfaction.

(4) Nomenclature. In the body of the book, the meaning of such terms as phosphorus, phosphoric acid, potassium, potash, calcium, lime, etc., has been discussed in some detail. In the older literature we find, for example, only such terms as phosphoric acid, potash, and lime, while in recent literature we find more or less common the terms, phosphorus, potassium and calcium. Under the circumstances, it is obviously in the interest of clearness to give both forms, when speaking of definite amounts; therefore, we have generally given figures showing the equivalent amounts of both phosphorus and phosphoric acid, of potassium and potash, of calcium and lime.

(5) Illustrations. Most of the illustrations used in this book represent some form of investigation work carried on by the agricultural experiment stations and colleges of the United States and by the United States Department of Agriculture, especially the Bureau of Plant Industry and the Bureau of Soils. The author desires to express his appreciation of the generous co-operation which he has met in collecting these illustrations; material, when available, has been furnished in case of every request. He is under obligation also to the Orange Judd Company for assistance rendered in obtaining some of the illustrations.

(6) Use of the book. In the selection and arrangement of the materials, the writer has kept in mind the needs of practical farmers as well as those of classes in agricultural colleges and high schools. The book can be used to advantage in the educational work of granges and other farmers' clubs. Frequent cross-references are given to assist the student in reviewing parts gone over

previously or to furnish needed explanation in case one does not read the chapters in the order given.

The author appreciates the difficulty of wholly eliminating errors in a work involving so many and varied details. He will regard it as a favor to have his attention called to any defects, whether in the matter of omissions, imperfect treatment or inaccuracy of statement, which may be found by those who use this book.

In the preparation of Chapters XXXIII and XXXIV, valuable assistance has been received from Prof. U. P. Hedrick, Horticulturist of the New York Agricultural Experiment Station. Helpful suggestions have also been made by Mr. J. F. Barker, in charge of soil investigations at the New York Agricultural Experiment Station.

Geneva, N. Y., January 15, 1912.

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CHAPTER I

INTRODUCTION: CONSERVATION OF PLANT-FOOD—RELATIONS OF PLANT-FOOD TO SOIL FERTILITY

There has never been in this country so widespread and so deep an interest in the subject of conservation of plant-food as at the present time; and never before have so many men, trained for investigation, been engaged in studying the subject in all its manifold phases and varied relations.

The condition of many American farmers is aptly illustrated in the following experience described by Dr. Holmes in "The Professor at the Breakfast Table": "Let me tell you what happened to me once. I put a little money into a bank, and bought a check-book, so that I might draw it as I wanted, in sums to suit. Things went on nicely for a time; scratching with a pen was as easy as rubbing Aladdin's Lamp; and my blank check-book seemed a dictionary of possibilities, in which I could find all the synonyms of happiness, and realize any one of them on the spot. A check came back to me at last with these two words on it—*No funds*."

The application of the foregoing experience is, in its main features, so highly suggestive as to require no special explanation. The methods pursued by American farmers in drawing upon the readily available plant-food supplies deposited for their use by the accumulations of long ages have been wasteful if not yet exhaustive. The main problem before our farmers is, therefore, the utilization of plant-food under such conditions and methods as will stop needless waste and at the same time increase the average yield of crops without a proportionate increase of cost. It

may seem paradoxical to suggest that it is possible to produce larger crops without using up more rapidly the soil's supply of plant-food. Speaking in general terms, it becomes a matter of preventing unnecessary losses of plant-food materials, and, at the same time, of replacing unavoidable losses in the most economical way, while maintaining such other conditions requisite for plant growth as will permit crops to utilize to greatest advantage the food supplies within reach.

While much attention has been publicly directed to the conservation of our phosphate deposits, and most wisely so, the real field for conservation, the one that furnishes the most extensive and important opportunity for the effective practice of conservation of plant-food, is the American farm. Each farmer has at his own door opportunities for the study and practice of conservation, and each must for himself apply in his work the principles which will aid in the solution of his immediate problems. Fortunately, trained investigators have done much to point the way in which true conservation lies, though some details yet remain to be worked out.

The controllable losses of plant-food on American farms are fairly appalling, taken in the aggregate. To give, as an illustration, the loss from only a single source, it is a moderate statement, well within the limits of actual truth, that one-third of the plant-food value of the manure produced by the different kinds of farm animals in the United States is lost by carelessness, a loss equivalent to $700,000,000 a year; and most of this enormous waste, equal in value to an average annual wheat crop, *is preventable.*

The wasteful methods of crop raising and the neglect of ordinary precautions in saving and utilizing the farm resources have led to increasing dependence upon the blind use of commercial fertilizers; this practice has developed in too many cases into a habit not unlike the patent-medicine habit, so far as relates to knowledge of

the materials used and intelligent reasons underlying their use. Millions of dollars have been thrown away in using commercial fertilizers, because the conditions which make their use most effective have not been appreciated or understood by farmers.

Generally speaking, the fundamental purpose of this book is to study the conditions under which plant-foods, whether in the form of soil compounds, or of farm-produced materials, or of commercial fertilizers, can be conserved and at the same time utilized with the greatest efficiency and economy in the production of crops.

PLANT-FOOD

Plant-feeding is not a simple problem. Its solution depends upon much more than the liberal use of farm manure, commercial fertilizers or other materials. Intelligent and successful use of plant-foods in the growing of crops is based upon knowledge of definite facts and of the relations of these facts to one another. As we shall learn later, the beneficial action of fertilizers upon crops depends upon, and is limited by, many different conditions, each of which must be taken into careful consideration if the cost of crop production is to be satisfactorily regulated. The main purpose of this introductory chapter is to make prominent at the beginning some of the important fundamental facts which underlie the practical problem of feeding crops.

We shall have occasion to use frequently such terms as *plant-food, available, unavailable, soil fertility,* etc., and it is desirable that we define them in the beginning, or at least make an attempt; although the details of our definitions in their various applications will be discussed more or less constantly throughout the subsequent chapters of the book, and their meaning made clearer by more complete development.

As commonly used, the term, *plant-food,* includes com-

pounds containing nitrogen, phosphorus or potassium; this use has arisen, as will be pointed out later (p. 242), because these constituents are the only ones that have been usually considered in connection with the application of fertilizers in the growing of crops. This limited application of the term answers some practical purposes, but is not sufficiently broad to be accurate. For the purposes of this treatise, *a plant-food can be defined as a substance which supplies any constituent necessary for the nourishment of plants and in a form suited to promote their development or capable of being changed by natural processes into such a form.*

We shall later learn in detail what are the different constituents that are essential to the nutrition of plants and also what are the particular forms or compounds containing these essential constituents that plants can utilize for their growth. For the present it is sufficient to state that the air and the earth's surface are the original sources of all plant-foods.

It will be shown later (p. 164) that a substance must enter a plant before it can be used as food. Gases and liquids are able to enter plants readily, but solids must be brought into the form of solution in water before they can do so. The solid compounds that contain plant-food constituents vary greatly in respect to the quickness and completeness with which they dissolve in water. Some compounds must be changed into other forms of combination before they are soluble in water. It is, however, not sufficient merely that compounds containing plant-food constituents should be soluble in water in order to serve as plant-food. Many such soluble substances, even after they get inside the plant, are not used as a source of nourishment, though containing an abundance of some plant-food constituent. As we shall later see more fully, the number of substances that are in forms suited to promote plant development at once, or that are capable

of being changed into such forms, is comparatively small, especially if we limit the number to those that are practically or commercially important. To distinguish substances containing plant-food constituents that are in forms suited to promote plant development, or that are capable of being more or less readily changed into such forms, from those that are not in such forms and do not easily change, we use the terms *available* and *unavailable*. The common usage of these terms has been somewhat confusing, and necessarily so, because the line of division is obscure and must be more or less arbitrary, at least in many cases. The property of availability is dependent on so many complicated conditions, that it is well nigh impossible to give a definition that will cover all possible cases. Moreover, full comprehension of any adequate definition can be gained only by study of subsequent chapters.

Available plant-food.—*A plant-food, or a plant-food constituent, is available when it is in such form of combination that plants can immediately utilize it, or when it is in such form that, though not suited to immediate use, it becomes so more or less readily under favorable conditions.*

Unavailable plant-food.—*A plant-food, or a plant-food constituent, is unavailable when it is in such form of combination that plants cannot utilize it under any natural conditions, or when it becomes available so slowly under favorable conditions as not to furnish appreciable amounts of material that can be used by growing crops.*

We will now try to explain the meaning of these definitions as far as possible at this stage of our study by means of specific illustrations.

(1) *Plant-food immediately available.*—Nitrogen in the combination known as *nitrate* (p. 40) furnishes a typical case of *immediately available* plant-food. Of the large number of compounds containing the essential plant-food constituent, nitrogen, the one form of chemical combina-

tion which plants use most quickly and extensively as food is that of nitrate nitrogen. It is a significant fact also that all nitrate combinations present in soils are easily soluble in water. Similarly, the *phosphorus* and *calcium* in acid calcium phosphate (p. 47) and the *potassium* in potassium chloride (muriate of potash), or in potassium sulphate or carbonate (p. 51), are available, because these compounds readily dissolve in water and can be

EXPERIMENT PLATS. PENNSYLVANIA STATION

taken into plants at once for use as food without having to be changed into other forms of chemical combination.

(2) *Plant-food not immediately available.*—Organic materials containing nitrogen, such, for example, as dried blood, fish-scrap, cottonseed-meal, etc. (p. 429), are not soluble in water to any marked extent and cannot, therefore, be used at once as plant-food; but under the action of micro-organisms (p. 204) their nitrogen is changed into nitrate nitrogen under favorable conditions, the

rapidity of the change depending upon temperature, moisture, kind and number of micro-organisms, fineness of plant-food material, etc. Under usual conditions, the nitrogen in such substances, when applied to soils in spring, becomes completely available in time to be used by crops during the growing season. While not immediately available, the nitrogen in such materials is classed as available, and is actually so from the practical standpoint of supplying the needs of growing crops.

As a further illustration under this head, let us take farm manure. When strictly fresh it contains no immediately available plant-food. As it passes through various processes of fermentation changes under the action of micro-organisms, its plant-food constituents gradually pass into immediately available form, beginning with the liquid portion and in time extending to the solid part. When applied to soils in sufficient amount, farm manure usually continues to show beneficial effects on crop growth for three or four years, corresponding with the change of slowly available plant-food constituents into forms immediately available.

(3) *Compounds wholly unavailable.*—There are many compounds containing constituents essential to plant growth that are readily soluble in water but, if taken into the plant, they are not used as food; in some cases compounds of this kind, even in very minute amounts, act as poisons and seriously interfere with the normal activities of plants. When such substances, even though containing constituents essential to plant nutrition and readily soluble in water, are not capable of change under ordinary conditions into compounds that plants can use as food, they are wholly unavailable—in fact, they are not plant-foods at all. As illustrations of such forms of compounds we may mention potassium cyanide, calcium or magnesium chloride in solutions not sufficiently dilute.

(4) *Plant-food constituents largely unavailable.*—When

the term *unavailable* is applied to materials containing plant-food constituents, it is usually in the sense of *very slowly available.* In illustration of this class of substances, we can mention some familiar organic materials that contain considerable percentages of nitrogen, such as leather or hair. These substances show great power of resistance to the action of micro-organisms and their nitrogen is changed into nitrate with extreme slowness, requiring many years for complete conversion into available form. Such substances become available so slowly as to be of little value in furnishing plant-food for growing crops. For practical purposes, these materials are regarded as unavailable or inert. Similarly, iron and aluminum phosphates (p. 49), which constitute a large portion of the phosphate compounds in many soils, are so slowly changed under ordinary conditions into forms that a plant can use that they are classed as unavailable.

Strictly speaking, a plant-food constituent in unavailable form is not *actual* plant-food at all, but is simply raw material which under proper conditions may become actual plant-food in time. Unavailable plant-food is, therefore, regarded as *potential* plant-food, that is, an existing source of future supply of *actual* plant-food. As we shall appreciate later, unavailable plant-foods are constantly becoming available, and control of the processes of converting potential into actual plant-food constitutes one of the fundamental problems of successful crop production. The conditions under which unavailable is changed into available plant-food constitute a most important line of study in future chapters.

Factors affecting availability of plant-food.—The subject of availability of plant-food is in many cases even more complicated than might appear from the preceding discussion, since many factors must be taken into consideration. These will be considered in detail later in connection with individual materials (p. 426), but we will

anticipate to the extent of simply stating at this point without enlargement that, prominent among the factors affecting the availability of plant-foods, are the following: (1) The chemical character of the plant-food materials, (2) their fineness of division, (3) various soil conditions, especially those affecting its micro-organisms, and (4) the character of the crop grown.

With this preliminary and necessarily superficial consideration of the subject of plant-food availability, we leave it only to resume it in more detail here and there throughout the book.

FACTORS OF SOIL FERTILITY

In common usage, we speak of a soil as fertile when it produces large crops. The expression, soil fertility, is used to include the factors that make a soil productive; definitions vary in respect to the factors included. The most common meaning given to soil fertility is simply abundance of available plant-food in the soil. This is too narrow, since, as we shall see later, a soil may contain available plant-food sufficient to meet the requirements of large crops and yet be unproductive. The broadest possible use of the term, soil fertility, includes all conditions that affect crop production, not only those more immediately centered in the soil itself, but also those outside, such as rainfall, temperature, adaptation of crops to soil and climate, selection of seed, and all other factors that may be regarded as external.

While we can speak of the factors of soil fertility as being divided into two general classes, internal and external, they are so closely bound together in crop production that we can separate them only in theory. When we speak of a soil as fertile, we always assume that the external factors, rain, sunshine, seed, etc., are present to furnish favorable conditions for crop growth, supplementing those of the soil.

As a general statement, we can say that *under the term, soil fertility, we include all the factors in the soil that contribute to plant growth when supplemented by favorable external conditions; the ability of a soil to produce crops under conditions favorable to plant growth is a measure of its fertility.*

The conditions needed in a soil to promote plant growth are the following: (1) Abundance of available plant-food. (2) A physical structure (a) which combines mellowness and firmness, permitting plant-roots to extend their growth freely; (b) which enables the soil to receive water easily, distribute it promptly, hold it with sufficient tenacity, and give it up as needed by plants; (c) which permits some circulation of air; and (d) which makes the soil able to absorb heat and maintain a degree of warmth suited to plant growth. (3) The presence of beneficial micro-organisms and conditions favorable to their growth. (4) Absence of injurious amounts of substances poisonous to plants.

The factors of soil fertility, to which we shall give attention in subsequent chapters, are conveniently grouped under three general divisions, as follows:

(1) *Chemical composition,* or the relations of soils to (a) the kinds and amounts of plant-food present and (b) substances injurious to plant growth.

(2) *Physical condition,* or the relations of soils to air, moisture, heat and light.

(3) *Biochemical condition,* or the relations of soils to the action of micro-organisms.

RELATION OF PLANT-FOOD TO OTHER FACTORS OF SOIL FERTILITY

The fact that soil fertility is so generally regarded as synonymous with an abundance of available plant-food has a certain amount of justification, since it is a fact worthy of notice that plant-food appears to be the one

factor to which others are, in a sense, more or less largely subordinated. Someone has defined an animal as a stomach with appendages necessary for feeding it. In a somewhat similar way, a plant can be regarded as an organism furnished with an environment whose factors combine to prepare and supply food for it. The insoluble plant-

FERTILIZER EXPERIMENTS WITH SOIL IN POTS.
NEW JERSEY STATION

food constituents of the rock-crust of the earth have been pulverized by various natural agencies (p. 90), and have been made soluble as the result of the chemical action of water, carbon dioxide (carbonic acid) and oxygen (p. 91), together with the help of micro-organisms (p. 228); various agencies combine to make the soil mellow so that the plant-roots can find their way to the supplies of plant-food (p. 102); water holds plant-food in solution ready for absorption by plant-roots, carrying it into and throughout the plant (p. 145). And so, chemical,

physical and biological factors, all combine to prepare the plant-food supply. Those conditions of soil that are recognized as best suited to crop production are the ones which best furnish available plant-food. It follows, therefore, that the preparation and utilization of plant-food are dependent upon many factors, all of which must be taken into consideration in any practical discussion of plant-feeding. In discussing the use of fertilizers in the growing of crops, we must, then, keep in mind that certain conditions are essential before a crop can use plant-food to advantage, whether in the form of an applied fertilizer or in the form of plant-food derived directly from the soil. Various conditions limit and determine the effect of plant-food. Some of the factors are more or less largely beyond man's control, while others are within his power to regulate. Among the most important specific factors, capable of control, which affect the usefulness of plant-foods in crop growing, are the following:

(1) Soil organic matter.
(2) Soil moisture.
(3) Soil acidity.
(4) Soil structure.
(5) Soil micro-organisms.

It is obvious that any treatment relating to the use of fertilizers must be narrow and superficial and in the nature of an ordinary recipe, which confines itself to a statement of how many pounds of nitrogen, phosphorus, or potassium compounds to apply to crops. Therefore, in the preparation of this book, it has seemed necessary to consider first the factors determining the effectiveness of fertilizers before we can consider to advantage their practical use in crop-growing; and we shall proceed with this purpose in mind, giving attention to the various factors of soil fertility, in so far as such a study will enable us to appreciate their practical relations.

CHAPTER II

THE CHEMICAL ELEMENTS OF PLANTS

In our study of plant-foods, we shall take as our starting-point the constituents that are found necessary for the growth of plants; we shall study briefly their sources, compounds, properties and functions.

CHEMICAL ELEMENTS

All forms of matter known to us are composed of about eighty different chemical elements, that is, of substances which cannot, by any known means, be separated into two or more different kinds of matter. For example, pure sulphur is an element because, whatever processes we may put it through, we cannot get anything out of it but sulphur; pure sulphur contains nothing but sulphur. Similarly, nitrogen is an element because no one has ever been able to show that it contains more than one thing, nitrogen. Other examples of chemical elements are oxygen, carbon, phosphorus, iron, calcium, etc. Some of the elements, as commonly known to us, are gases, such as oxygen and nitrogen, but most of them under ordinary conditions are solids.

Chemical elements in plants.—The many thousands of different kinds of plants growing on the earth, with all their variation of stem, foliage, flower and fruit, are made from a comparatively few elements. Of the eighty different elements known, the following, fourteen in number, commonly occur in plants: Calcium, carbon, chlorine, hydrogen, iron, magnesium, manganese, nitrogen, oxygen, phosphorus, potassium, silicon, sodium and sulphur. In regard to the elements found in plants, we notice the following general points of interest:

(1) *Unequal proportions.*—These elements occur in very unequal amounts in the vegetable world. For example, carbon, oxygen and hydrogen, taken together, alone make up over 95 per cent, on the average, of all plants.

(2) *Unequal importance.*—These 14 elements are not of equal importance to plant life. It has not yet been satisfactorily demonstrated that chlorine, manganese, silicon and sodium perform any necessary function in plant growth, unless, perhaps, in isolated, exceptional and doubtful cases.

(3) *Number of essential elements.*—So far as we actually know at present, it is not remote from the truth to say that only 10 chemical elements are really essential to plant growth under ordinary conditions.

(4) *Accidental elements.*—Other elements, though in no way essential to plant life, occur under special conditions more or less frequently in plants; among these may be mentioned aluminum, arsenic, barium, boron, bromine, copper, fluorine, iodine, lead, lithium, nickel, tin and zinc, but their occurrence is a matter of general interest rather than agricultural importance. Such substances may be regarded as straying into a plant without purpose or plan simply because they happen to be in solution in the neighborhood of growing plant-roots and go into the plant in company with plant-food proper (p. 166).

Air-derived and soil-derived elements.—The elements required by plants are divided into two quite distinct classes, which show important and marked differences. These two classes are *air-derived* elements and *soil-derived* or *mineral* elements, as shown in the following grouping:

(1) *Air-derived elements:* Carbon, Hydrogen, Nitrogen, Oxygen.

(2) *Soil-derived elements:* Calcium, Iron, Magnesium, Phosphorus, Potassium, Sulphur (Chlorine, Manganese, Silicon, Sodium).

These two classes of elements differ in three important points, as follows:

(1) *Source.*—The elements of one class come to plants exclusively from the air, it may be directly, or it may be indirectly through the medium of the soil. Elements of the second class come directly and exclusively from the soil.

(2) *Effect of burning.*—When a plant is completely burned, the air-derived elements disappear, for the most part, in the form of gases; the soil-derived or mineral elements, usually much the smaller part, are left in the form of an unburned residue or ash, upon which further heating has no effect. This distinction is not perfectly sharp, since some oxygen is always found in the ash, while a small amount of chlorine, phosphorus and sulphur may be driven off in the form of gases during the operation of burning.

(3) *Proportions in plants.*—Air-derived elements make up over 95 per cent. of the whole vegetable kingdom, while the soil-derived elements occur in small amounts, varying in different plants and in different parts of the same plant, from a fraction of 1 per cent. to 10 per cent., or even more in some cases, taking the plant as a whole. The following figures illustrate the preceding statements; the percentages are based on dry or water-free material:

TABLE I—DISTRIBUTION OF AIR-DERIVED AND SOIL-DERIVED ELEMENTS IN PLANTS

Name of plant	Air-derived elements	Soil-derived elements
Beets, roots	96.0 per cent	4.0 per cent
" **leaves**	86.0 "	14.0 "
Corn (maize), leaves and stalks	94.5 "	5.5 "
" **grain**	98.5 "	1.5 "
Peas, vines and pods	95.0 "	5 0 "
" **seeds**	97.3 "	2.7 "
Oats, straw	93.0 "	7.0 "
" **grain**	97.0 "	3.0 "
Turnips, roots	92.0 "	8.0 "
" **leaves**	88.0 "	12.0 "
Wheat, straw	94.5 "	5.5 "
" **grain**	98.0 "	2.0 "

Because the soil-derived elements occur in small proportions, it does not follow that their presence is of slight importance; in their absence plants could not grow. This fact has a most important application in enabling us to influence the yield of crops. We cannot, to any appreciable extent, directly control, at least economically, most of the air-derived elements in the feeding of crops, but we can do so indirectly through the soil-derived elements. In other words, by controlling, under certain conditions, through the soil 5 per cent., and usually less, of the materials that enter into the composition of plants, we can, in large measure, control the other 95 per cent.

Elements and compounds.—The chemical elements do not commonly exist separately from one another as pure elements. While we are familiar with impure carbon in the form of coal and charcoal, and with nitrogen and oxygen as they are mixed together in the air, we never find under ordinary conditions elements like hydrogen, phosphorus, potassium, etc., existing separate from other elements. Different elements combine to form compounds somewhat as the different letters of the alphabet combine to form words. The few chemical elements used in plant growth exist in the air and soil in the form of compounds; some of these compounds are used as food by plants; after being taken into the living plant, they are worked over into a great variety of new compounds; and these new compounds, which have been formed within the plant, are more or less regularly grouped or mixed together in a great variety of ways in the processes of plant-building. The elements may, therefore, be regarded as the raw materials from which plant-foods come.

Classes of chemical compounds in plants.—As a matter of general interest, we will briefly mention some of the more important and common kinds of chemical compounds found in plants.

(1) *Water.*—This is the most abundant compound

found in fresh plants. We shall discuss this compound more fully in subsequent pages (pp. 145-160).

(2) *Carbohydrates.*—Under the general term of carbohydrates is included a most important and widely distributed group of compounds, each containing carbon, hydrogen and oxygen. The most common members of this class are sugar, starch, cellulose (cotton, flax, wood, etc.), vegetable gums (gum arabic, vegetable mucilage of seeds like flax and quince), and other compounds more or less familiar and useful.

(3) *Proteins.*—The class of plant compounds known as proteins (also often called proteids and albuminoids) is distinguished for containing constituents of great value in animal nutrition. In addition to the three elements contained in carbohydrates (carbon, hydrogen and oxygen), plant proteins contain nitrogen and generally sulphur, and some of them phosphorus also. As familiar representatives of this class, we have gluten (the sticky portion of wheat flour) and the so-called vegetable casein of beans and peas.

(4) *Oils.*—All plants contain some oil or oils, many of which are of commercial importance, such as linseed, castor, olive, cottonseed, etc. These contain the elements, carbon, hydrogen and oxygen, but in relative proportions different from those occurring in carbohydrates.

(5) *Acids.*—Many of the vegetable acids and their acid salts are important articles of commerce. Their presence in many fruits accounts for the special dietetic value of such fruits. Among the more common vegetable acids are: (a) tartaric acid, found in grapes; (b) citric acid, present in lemons, currants, cherries, strawberries and similar fruits; (c) malic acid, the characteristic acid of apples, tomatoes and several small fruits. These acids contain the elements, hydrogen, carbon and oxygen, combined in different proportions.

(6) *Aromatic substances.*—Most plants possess in their flowers, fruits, leaves and roots compounds having characteristic flavors. These are due frequently to volatile oils (consisting of carbon and hydrogen), such as oils of turpentine, lemon, cinnamon, almond, etc., or to other special plant compounds, among which may be mentioned the characteristic flavors of pineapple, apple, strawberry, banana, wintergreen, mints, etc., which usually contain the three elements, carbon, hydrogen and oxygen.

(7) *Medicinal substances.*—There is a large variety of very widely distributed substances used especially for medicinal purposes, among which, for example, are morphine (from the poppy), quinine (from cinchona bark), nicotine (from tobacco), strychnine (from seeds of strychnos nux-vomica), belladonna (from deadly nightshade), etc.

(8) *Mineral compounds.*—It is noticeable that the preceding classes of plant compounds are made up chiefly of air-derived elements and are, for the most part, among the most important articles of commerce. The soil-derived or mineral elements are present in the plant largely in the form of combinations known as salts, such as carbonates, chlorides, phosphates and sulphates of potassium, calcium (lime), magnesium, iron, sodium, etc. (p. 106). These mineral compounds exist in the tissues of plants in three general forms: (1) In solution in the plant juice or sap, (2) in the form of crystals in plant cells, and (3) as incrustations in the cell walls.

Relative agricultural importance of different elements.—While the absence of any one essential constituent seriously impairs or wholly prevents plant growth, there is a sense in which some of the soil-derived elements are of much greater agricultural importance than others. Certain ones are more extensively used by crops and sooner or later require special attention in the way of increasing the available supply, while others are used in

such small amounts, relative to the available supply, that they rarely need attention. The elements of such special importance are the following: **Nitrogen, Phosphorus, Potassium and Calcium.**

CHAPTER III

SOME FUNDAMENTAL FACTS OF CHEMISTRY[1]

As material for study in the case of anyone who desires to gain an understanding of a few chemical facts of importance, and as a source of reference for those who wish to refresh their previous knowledge, we will, before continuing our study of the sources, compounds and functions of plant-food elements, present briefly some of the simpler, fundamental facts of chemical combination, which have a direct bearing on the subject of plant-foods in some of their chemical relations. We shall try to explain, necessarily in a superficial and simple way, the meaning and use of chemical symbols and names; it is desirable to get some idea, even though crude and limited, of what is meant by such terms as acid, alkali, base, salt, chemical neutralization, reaction, etc.

Symbols and combining proportions of elements.—As a matter of convenience in saving the labor of writing in full the names of elements and chemical compounds every time they are used, a kind of chemical short-hand system has been adopted, in which the name of each element is represented by a characteristic symbol, consisting of the first letter or letters of the name of the element; and where the English name differs from the Latin name, the letters of the symbol are taken from the Latin form. In the table following, we include simply those elements in which we are interested.

[1]For those who do not desire any knowledge of chemistry, this chapter may be omitted in reading. For others who desire to become acquainted with some of the simpler fundamental facts of chemistry, such as will give them a clearer understanding of the various relations of plant-foods, this chapter is recommended for serious study, especially in connection with subsequent chapters. It will be well to refer to it from time to time until its contents are familiar. Teachers using the book in class work with students who have not studied chemistry can exercise their judgment as to the way in which this chapter shall be used. For a complete understanding of parts of Chapter IV, this chapter is necessary.

We have mentioned the fact that elements combine to form compounds; it is a fact of great importance that in combining with one another, elements unite in certain definite weights or proportions. Each chemical compound always contains the same elements in exactly the same proportions. By analyzing large numbers of the compounds of different elements, a number has been found for each element which represents the proportion by weight in which it enters into combination with others. In the following table we give the names of those elements in which we are interested, their symbols and their approximate combining weights.

TABLE 2—NAMES, SYMBOLS AND COMBINING WEIGHTS OF CHEMICAL ELEMENTS

Name of element	Symbol	Combining weight
Hydrogen	H	1
Carbon	C	12
Nitrogen	N	14
Oxygen	O	16
Sodium (Latin, *Natrium*)	Na	23
Magnesium	Mg	24
Aluminum	Al	27
Silicon	Si	28.5
Phosphorus	P	31
Sulphur	S	32
Chlorine	Cl	35.5
Potassium (Latin, *Kalium*)	K	39
Calcium	Ca	40
Manganese	Mn	55
Iron (Latin, *Ferrum*)	Fe	56

The chemical symbol of an element is seen to stand for two things, (1st) for the name of the element and (2d) for the combining weight. We will explain more fully the point of combining weights. The compound known chemically as sodium chloride, which is familiar to us as common salt, has its composition shown by the symbol or formula, NaCl, in which 23 parts by weight of sodium, its combining weight, are always combined with 35.5 parts by weight of chlorine, no more and no less, 35.5 being the combining weight of Cl. In calcium oxide, commonly known as lime, the symbol or formula, CaO, means

that 40 parts by weight of calcium are always united with exactly 16 parts by weight of oxygen. It should be stated further that the combining weight always represents the *smallest amount* of an element that enters into combination. In other words, we do not have half of a combining weight but always the full value given in the table above. This fact depends upon certain reasons which we cannot take time to discuss. Taking 1 as the combining weight of hydrogen (H), the lightest element, the other combining weights are those stated in Table 2.

In many compounds, one or more elements may be combined in a proportion representing two or more times the combining weight given in the preceding table. For example, in the case of water we have 2 parts by weight of hydrogen (H) and 16 parts by weight of oxygen (O); this is conveniently expressed by the formula, H_2O (equal to HHO). Whenever an element is used in proportions representing more than one combining weight, this fact is expressed by writing the corresponding number below and at the right hand of the symbol of the element. This is further illustrated in the case of nitric acid, HNO_3 (equal to HNOOO), in which we have 1 part (1 combining weight) of hydrogen, 14 parts (1 combining weight) of nitrogen and 48 parts (3 combining weights, 3×16) of oxygen. Again, in the compound sodium phosphate, Na_3PO_4 (equal to NaNaNaPOOOO), we have 3 combining weights of sodium, 1 of phosphorus and 4 of oxygen; or, expressed in parts by weight, 69 (23×3) parts of sodium, 31 parts of phosphorus and 64 (16×4) parts of oxygen.

In this connection, it is desirable to point out a mistake that is often made in respect to the meaning of chemical formulas by those who have not studied chemistry. Take for illustration the compound last mentioned, Na_3PO_4; by some this would erroneously be taken to mean 3 parts of sodium, 1 part of phosphorus and 4 parts of oxygen,

which is very far from the truth, since the symbol of an element stands, not for equal parts, but for *combining weights*, and no two elements have the same combining weight. If the combining weights of different elements were the same, then it would be proper to speak of the symbols in the formula Na_3PO_4 as representing 3, 1 and 4 parts respectively of the elements in question; but since these symbols represent different weights, the compound contains by weight, as a matter of fact, 69 parts (3 combining weights) of sodium, 31 parts (1 combining weight) of phosphorus and 64 parts (4 combining weights) of oxygen.

How to calculate percentages of elements in a compound.—When we know (1) the chemical formula of any compound and (2) the combining weight of each element in the compound, we can easily calculate the percentage of each constituent element. Take, for illustration, potassium chloride (muriate of potash); its composition is expressed by the symbol KCl, containing, according to the combining weights given on page 23, 39 parts by weight of K and 35.5 parts of Cl. In order to find the percentage of each element in KCl, we add the combining weights of the K and Cl, multiply each by 100 and then divide each result by the sum of the combining weights of K and Cl. The operations can be conveniently shown as follows:

(1)	Combining weight of K = 39	
(2)	" " " Cl = 35.5	
(3)	Sum of combining weights of K + Cl = 74.5	
(4)	(K) 39 × 100 + 74.5 = 52.3	the percentage of K in KCl
(5)	(Cl) 35.5 × 100 + 74.5 = 47.7	" " Cl. "

We will take three other cases for further illustration: (1) Sodium nitrate (nitrate of soda), (2) potassium sulphate and (3) calcium phosphate.

Example 1.—Find the percentages of different elements in sodium nitrate, $NaNO_3$.

(1) Combining weight of Na = 23
(2) " " " N = 14
(3) " " " O_3 = 48 (16 × 3)

(4) Sum of combining weights of Na + N + O_3 = 85
(5) (Na) 23 × 100 ÷ 85 = 27, the percentage of Na in $NaNO_3$
(6) (N) 14 × 100 ÷ 85 = 16.5 " " N " "
(7) (O_3) 48 × 100 ÷ 85 = 56.5 " " O " "

Example 2.—Find the percentages of different elements in potassium sulphate, K_2SO_4.

(1) Combining weight of K_2 = 78 (39 × 2)
(2) " " " S = 32
(3) " " " O_4 = 64 (16 × 4)

(4) Sum of combining weights of K_2 + S + O_4 = 174
(5) (K_2) 78 × 100 ÷ 174 = 44.8, the percentage of K in K_2SO_4
(6) (S) 32 × 100 ÷ 174 = 18.4 " " S " "
(7) (O_4) 64 × 100 ÷ 174 = 36.8 " " O " "

Example 3.—Find the percentages of different elements in calcium phosphate, $Ca_3P_2O_8$.

(1) Combining weight of Ca_3 = 120 (40 × 3)
(2) " " P_2 = 62 (31 × 2)
(3) " " O_8 = 128 (16 × 8)

(4) Sum of combining weights of Ca_3 + P_2 + O_8 = 310
(5) (Ca_3) 120 × 100 ÷ 310 = 38.7, percentage of Ca in $Ca_3P_2O_8$
(6) (P_2) 62 × 100 ÷ 310 = 20.0, " " P " "
(7) (O_8) 128 × 100 ÷ 310 = 41.3, " " O " "

A careful study of the preceding examples will enable one easily to make use of the following rule: To find the percentage of any constituent of a chemical compound, when the chemical symbol or formula is known, *first find in Table 2 the combining weight for each element represented in the compound, taking the combining weight of each element as many times as is indicated in the formula. Add the combining weights thus obtained. Then divide this sum into the combining weight or weights of each element present, multiplied by 100.*

Chemical action of acids and bases.—Caustic soda or soda lye, a material familiar in many common uses, is known in chemistry as *sodium hydroxide*, having the com-

position represented by the symbol NaHO; it is also known as a *base*, an *alkali*, and an *alkali base*, the meaning of which terms we will consider later. This substance, when added to an acid, produces some very noticeable changes. For example, if we add together solutions of some nitric acid (HNO_3) and of sodium hydroxide in certain proportions, we shall have as a result neither nitric acid nor sodium hydroxide, but a new compound, *sodium nitrate* ($NaNO_3$), which has been formed by the action of the acid and alkali upon each other. The nitric acid used in the experiment tastes sour and biting, while the caustic soda solution has a peculiar odor and feels soapy on the hands, and, if concentrated enough, destroys or "eats" the skin. After these two compounds in solution are brought together in the right proportions, there can be no longer observed any sour taste of acid, or soapy feeling, or alkali odor of the caustic soda, because the acid and alkali have *neutralized*, or in popular language "killed," each other, which means that they have combined to form entirely new compounds; in this case the new compounds are water (H_2O) and sodium nitrate ($NaNO_3$), this latter belonging to a class of chemical compounds known as *salts*. The presence of the nitrate is readily perceived by its characteristic salty taste. This chemical change or reaction can be represented by means of a chemical equation, as follows:

$$\underset{\text{Sodium hydroxide}}{\mathrm{Na}\,\boxed{\mathrm{HO} \quad + \quad \mathrm{H}}}\ \underset{\text{Nitric acid}}{\mathrm{NO_3}} = \underset{\text{Sodium nitrate}}{\mathrm{NaNO_3}} + \underset{\text{Water}}{\mathrm{H_2O}}$$

A good many important and practical facts of chemistry are illustrated by this simple change. We are at once met by such questions as the following: What is a base or an alkali? What is an acid? What kind of a product is formed in bringing together a base or an alkali and an acid?

Acid, alkaline and neutral reactions.—We will first

inquire how we can tell a solution of a base from one of an acid in a practical way. This is done by means of some coloring substance, called an indicator, which is so acted on by alkalis and acids as to undergo changes of color, producing one color with alkalis and a different color with acids. For example, one substance in common use as an indicator is the dyestuff known as *litmus*, which is blue. If we put a few drops of a litmus solution in some water and then add one or two drops of some acid, the color changes to red. If now the red solution is treated with a few drops of a solution of a base like sodium hydroxide, the red color disappears and the solution again becomes blue. For ordinary uses, such as testing acidity of soils (p. 142), litmus is used in the form of strips of paper colored red or blue with litmus dye. To use litmus paper for the purpose of testing whether a substance is basic (alkaline) or acid, a strip each of blue litmus and red litmus paper is put into the solution tested; if the blue strip changes to red, the solution is acid; if the red changes to blue, the solution contains a base or alkali; if neither color changes, the solution contains neither acid nor alkali. The behavior of any solution to litmus, or to any other indicator used for acids and alkalis, is described by calling it (1) *acid*, (2) *alkaline* or *basic*, or (3) *neutral*. The reaction is acid when blue litmus is changed to red; it is alkaline or basic, when red litmus is changed to blue; and it is neutral when the color of neither red nor blue is changed. A reaction is called *strong* when the color change is quick and very pronounced. Solutions reacting thus are called strongly acid or strongly alkaline. A reaction is called *weak* when the color change is slow or not very pronounced. Solutions acting thus are said to be weakly acid or weakly alkaline. The strong or weak character of the reaction of a solution depends primarily upon the amount of the alkali or acid in solution.

Making application of these statements to the illustration given above in the action of sodium hydroxide and nitric acid, sodium hydroxide turns red litmus blue and is alkaline or basic in reaction; nitric acid turns blue litmus red and its reaction is acid; the mixture of water and sodium nitrate, which are the products formed by the action of sodium hydroxide and nitric acid, has no effect upon either red or blue litmus and is therefore neutral in reaction.

We are now better prepared to take up for more detailed consideration the chemical character of substances such as bases, acids and the products formed by the action of bases and acids.

Bases *are compounds which have the power of neutralizing acids and thereby forming neutral salts.* The compounds that act most commonly as bases are the *hydroxides* and *oxides* of certain elements known as metals, which are called *base-forming* elements. The bases of most interest to us are the following:

TABLE 3—NAMES AND SYMBOLS OF COMMON BASES

Name of base	Symbol	Common name
Sodium hydroxide	$NaHO$	Caustic soda
Potassium hydroxide	KHO	Caustic potash
Ammonium hydroxide	$(NH_4)HO$	Ammonia water
Calcium hydroxide	CaH_2O_2	Slaked, caustic or hydrated lime
Calcium oxide	CaO	Lime, quicklime, etc.
Magnesium hydroxide	MgH_2O_2	Hydrated magnesia
Magnesium oxide	MgO.	Magnesia

Attention should be called to the *ammonium* compound. The elements nitrogen and hydrogen, taken in the proportions represented by the symbol NH_4, act together as if one element, and the combination resembles metals in forming basic and other compounds.

(1) *Alkalis.*—Of the different bases mentioned in the preceding list, potassium, sodium and ammonium hydroxides are called *alkalis* or *alkali bases;* their solutions have a strongly alkaline reaction, as shown by quickly chang-

ing red litmus to blue, even when present in small amounts. The alkalis possess very marked power in neutralizing acids, and for this reason are said to be strong bases or strongly basic.

(2) *Alkaline earths.*—Calcium and magnesium belong to a group of elements often called *alkaline earths*, because their oxides and hydroxides have an alkaline reaction. While their power to neutralize acids is not so great as that of the alkalis, they are more strongly basic than are the bases of many other metals.

(3) *Carbonates with basic power.*—The compounds known as carbonates have the power to neutralize acids and are therefore basic. The alkali carbonates have an alkaline reaction, changing red litmus to blue. The most important carbonate in agriculture is calcium carbonate, $CaCO_3$ (carbonate of lime), on account of its vital relations to soils and crops (p. 373). The action of carbonates and acids is illustrated by the reaction represented in the following equation, in which the neutral compound, calcium nitrate, is formed as the most important product of the reaction.

$$\underset{\text{Calcium carbonate}}{CaCO_3} + \underset{\text{Nitric acid}}{2HNO_3} = \underset{\text{Calcium nitrate}}{Ca(NO_3)_2} + \underset{\text{Water}}{H_2O} + \underset{\text{Carbon dioxide}}{CO_2}$$

Acids *are compounds which have the power to neutralize bases and thereby form neutral salts;* solutions of acids turn blue litmus red. For our purpose, acids can be regarded as consisting of two chemical parts, (a) the element hydrogen (H) and (b) an acid-radical, consisting of one or more acid-forming elements. For example, hydrochloric acid, HCl, consists of (a) H and (b) Cl (acid-radical); nitric acid, HNO_3, consists of (a) H and (b) NO_3 (acid-radical); sulphuric acid, H_2SO_4, consists of (a) H_2 and (b) SO_4 (acid-radical); phosphoric acid, H_3PO_4, consists of (a) H_3 and (b) PO_4 (acid-radical).

These compounds are often spoken of as *free* acids; by

this is meant an acid unneutralized, or the acid itself, uncombined with any other element or elements, in distinction from a neutralized acid, or an acid in combination as a salt.

In Table 4 (p. 32) we give a list of the acid-forming elements, together with the formulas and names of those acids which possess special interest for us in our study of plant-food materials.

Salts.—We will next inquire what kind of a product is the chief one formed when bases and acids act on each other. We have already learned: (1) That a base consists of some basic element, generally a metal, in union with OH (forming an hydroxide) or with O (forming an oxide); (2) that acids are made up of (a) hydrogen (H) in union with (b) an acid-radical consisting of one or more acid-forming elements.

Now, when we bring acids and bases together, we obtain, as the result of the chemical change, two products, (1st) water (H_2O), and (2d) *a compound consisting of the metal of the base combined with the acid-radical of the acid; compounds made up in this way are called salts.* Let us illustrate these statements by means of some reactions of bases and acids, as represented by the following equations:

Bases — Acids — Salts

(1) $$Na\boxed{HO + H}Cl = NaCl + H_2O$$

Sodium hydroxide — Hydrochloric acid — Sodium chloride — Water

(2) $$Ca\boxed{H_2O_2 + H_2}CO_3 = CaCO_3 + 2H_2O$$

Calcium hydroxide — Carbonic acid — Calcium carbonate — Water

(3) $$Na\boxed{HO + H}NO_3 = NaNO_3 + H_2O$$

Sodium hydroxide — Nitric acid — Sodium nitrate — Water

(4) $$2K\boxed{HO + H_2}SO_4 = K_2SO_4 + 2H_2O$$

Potassium hydroxide — Sulphuric acid — Potassium sulphate — Water

In examining the preceding equations, we observe that in each case there is formed, in addition to water, a *salt*, consisting of (a) the metal of the base combined with (b) the acid-radical of the acid. The hydrogen of the acid combines with the hydrogen and oxygen (HO) of the base to form water (H_2O); the metal of the base, in forming a salt, takes the place of the hydrogen of the acid.

Many of the substances with which we have to deal in connection with plant-foods belong to this class of chemical compounds, which we call *salts*.

Names and symbols of acids and salts.—The scope of our brief and fragmentary treatment of the chemical facts under consideration does not permit us to go into full details in regard to the method of naming chemical compounds and of writing their symbols. The following tabulated arrangement gives (1) the names of the acid-forming elements, (2) the names and symbols of the more common acids formed from them, and (3) the names of the salts corresponding to the acids. This table, together with Table 5, will be found useful for future reference.

TABLE 4—ACID-FORMING ELEMENTS AND SOME OF THEIR ACIDS

Acid-forming elements	Names and symbols of acids		Names of salts formed from acids
Chlorine	Hydro-chlor-ic	HCl	Chlorides
Nitrogen	Nitr-ic	HNO_3	Nitrates
Sulphur	Hydro-sulphur-ic	H_2S	Sulphides
	Sulphur-ic	H_2SO_4	Sulphates
Carbon	Carbon-ic	H_2CO_3	Carbonates
Silicon	Silic-ic	H_2SiO_3	Silicates
Phosphorus	Phosphor-ic	H_3PO_4	Phosphates
Oxygen	....	......	....

In discussing the data contained in this table, we wish to call attention to the following points:

(1) *Names of acids.*—The names of all acids end in the syllable *ic*, which is added to the full or the shortened name of the acid-forming element in the acid. In the case of acids containing no oxygen, like HCl and H_2S, the name is formed by placing before the name of the acid-forming element the syllable *hydro-*, and after the element the syllable *-ic*; for example, hydro-chlor-ic acid, hydro-sulphur-ic acid.

It may be stated that in addition to these two simple forms of acids there are many other kinds formed from these same elements, distinguished by special modifications of composition and name, but we confine our attention to the forms of most interest to us.

We may also notice, in passing, that the element oxygen is present along with some other acid-forming element in most acids; the name oxygen, derived from two Greek words, means acid-producing. The presence or absence of oxygen in an acid is shown by the name of the acid, as previously explained.

(2) *Names of salts.*—Salts derived from the oxygen-containing acids in the list are designated by using first the name of the metal in the salt and adding to this the name of the acid, changing the last syllable from *-ic* to *-ate*. Salts derived from the acids in the list containing no oxygen are similarly named, except that they end in the syllable *-ide* instead of *-ate*; the prefix *hydro-* in the name of the acid is dropped in naming the salt.

(3) *Symbols of salts.*—Every metal, or base-forming element, or group of elements (like NH_4, for example) can form a salt with every acid, at least in theory. In the list below, we give as a matter of convenience for reference the symbols of some salts, many of which will sooner or later come to our attention in our future study.

TABLE 5—SALTS FORMED BY METALS AND ACIDS

Salts of Sodium	Salts of Potassium	Salts of Ammonium	Salts of Calcium	Salts of Magnesium	Names of Salts
$NaCl$	KCl	NH_4Cl	$CaCl_2$	$MgCl_2$	Chloride
$NaNO_3$	KNO_3	NH_4NO_3	$Ca(NO_3)_2$	$Mg(NO_3)_2$	Nitrate
Na_2S	K_2S	$(NH_4)_2S$	CaS	MgS	Sulphide
Na_2SO_4	K_2SO_4	$(NH_4)_2SO_4$	$CaSO_4$	$MgSO_4$	Sulphate
Na_2CO_3	K_2CO_3	$(NH_4)_2CO_3$	$CaCO_3$	$MgCO_3$	Carbonate
Na_2SiO_3	K_2SiO_3	$(NH_4)_2SiO_3$	$CaSiO_3$	$MgSiO_3$	Silicate
Na_3PO_4	K_3PO_4	$(NH_4)_3PO_4$	$Ca_3(PO_4)_2$	$Mg_3(PO_4)_2$	Phosphate

We will give a brief explanation of how to use this table in finding the name corresponding to the symbol of a salt, or in finding the symbol of a salt when the name is given. It may be stated that, as a general rule, the chemical name of a salt is intended to express the composition as closely as possible.

(a) Finding name of a salt: To find the name of the salt corresponding to any symbol in the table, take first the name of the metal at the head of the column in which the formula occurs and then add to it the name in the last column opposite the symbol. For example, to find the name of the salt whose symbol is Na_2SO_4, we find *sodium* at the head of the column and *sulphate* in the last column opposite; the name of the salt is sodium sulphate. Similarly, we find the name corresponding to K_3PO_4 to be potassium phosphate; $(NH_4)_2CO_3$, ammonium carbonate, etc.

(b) Finding symbol of a salt: To find the symbol corresponding to any given name of a chemical salt in the list, we look in the column under the name of the metal contained in the salt and then go down the column until we come to the symbol opposite the name in the last column that corresponds to the second part of the salt. For example, the formula for sodium phosphate is found in the column headed *sodium* in the line opposite the word *phosphate* of the last column; it is Na_3PO_4.

(c) Uniting or combining power of metals and acids

radicals as shown by acids and salts: One can readily write all the symbols of salts in the table by committing to memory the three following statements:

(1) In case of acids containing one H, as HCl and HNO_3, *one acid-radical* (-Cl or $-NO_3$) combines *with one Na* or *K* or NH_4; while *two* ($-Cl_2$, $-(NO_3)_2$) are required to unite with *one Ca* or *Mg*.

(2) In case of acids containing two H, as H_2S, H_2SO_4, H_2CO_3, etc., *one acid-radical* (-S or $-SO_4$ or $-CO_3$, etc.) combines with two of Na, K or NH_4 (Na_2, K_2, $(NH_4)_2$); while one acid-radical requires only *one Ca* or *Mg*.

(3) In case of acids containing three H, as H_3PO_4, *one acid-radical* ($-PO_4$) combines with *three* of *Na, K* or NH_4 (Na_3, K_3, $(NH_4)_3$); while with *Ca* or *Mg two acid-radicals* ($(PO_4)_2$) combine with *three Ca* or *Mg* (Ca_3, Mg_3).

The combination of Ca and Mg with $-PO_4$ is not as easily understood as the others, and we will now try to show why we take Ca_3 and $(PO_4)_2$ in writing the symbol of calcium phosphate. The combining power of Ca is 2 in comparison with $-PO_4$ as 3, or one $-PO_4$ equals 1½Ca; but since we cannot have a fraction connected with a symbol, such as $Ca_{1\ 1\text{-}2}PO_4$,we make the number even by multiplying both 1½Ca and PO_4 by 2, which gives us $Ca_3(PO_4)_2$. Explained another way, Ca has a combining power equal to H_2; one Ca would not be sufficient to equal H_3 in H_3PO_4 and Ca_2 would equal H_4 or more than H_3, but taking H_3PO_4 twice, we have $H_6(PO_4)_2$, and H_6 just equals the combining power of Ca_3, giving $Ca_3\ (PO_4)_2$. This point has been dwelt upon, because, if possible, it is desirable to understand this and other compounds of phosphoric acid.

(4) *Acid salts.*—In the case of acids having more than one H, it is possible to form two different salts with the same metal. For example, sulphuric acid can form two

salts with potassium, one of which is contained in the preceding table, viz., K_2SO_4, in which H_2 of H_2SO_4 has been replaced by K_2; the other potassium salt is formed by replacing one H of the acid by one K and leaving one H, making $KHSO_4$, which is known as potassium acid sulphate or potassium hydrogen sulphate. Such salts usually have an acid reaction.

In connection with our study of plant-foods, the most important case of acid salts is in connection with phosphoric acid, H_3PO_4. This can form three different salts with metals depending on whether the metal replaces the H_3 completely or only in part. For example, sodium can form three salts with phosphoric acid, because we can put the element Na one, two or three times in place of hydrogen (H_3), which is shown as follows:

(1)	$HHHPO_4$ or H_3PO_4	Phosphoric acid
(2)	$NaHHPO_4$, NaH_2PO_4,	one-sodium phosphate, or sodium acid phosphate
(3)	$NaNaHPO_4$, Na_2HPO_4,	two-sodium phosphate, or disodium hydrogen phosphate
(4)	$NaNaNaPO_4$, Na_3PO_4,	three-sodium phosphate, or neutral sodium phosphate

When we come to study the calcium salts of phosphoric acid in fertilizers, we find an important use of acid salts. Calcium forms three different phosphates with phosphoric acid. The formation of these salts is of the same character as shown above in case of sodium, except that since one Ca equals H_2 and has double the combining power of Na, we use twice as much phosphoric acid, $2H_3PO_4$. The following arrangement illustrates the relations of these salts:

(1)	$2H_3PO_4$ or $H_6(PO_4)_2$,	Phosphoric acid
(2)	$CaH_4(PO_4)_2$,	one-calcium phosphate, or mono-calcium phosphate (soluble, p. 45)
(3)	$Ca_2H_2(PO_4)_2$,	two-calcium phosphate, or di-calcium phosphate (reverted, p. 45)
(4)	$Ca_3(PO_4)_2$,	three-calcium phosphate, or tri-calcium phosphate (insoluble, p. 45)

Complex and simple compounds.—We shall have occasion to use the terms simple and complex with reference to chemical compounds, and it is desirable to define them. Compounds are simple when they consist of few ele-

ments in simplest combination, while complex compounds contain a larger number of elements or in larger aggregations. For example, hydrochloric acid (HCl) is the simplest compound possible, containing only two elements in the simplest combination possible. Calcium phosphate, $Ca_3(PO_4)_2$ is a more complex compound. Some of the silicates are very complex, containing half a dozen different elements. When we speak of a chemical compound decomposing or breaking down into simpler compounds, we mean that it forms several compounds, each with a smaller aggregation of elements. For example, ammonium carbonate, $(NH_4)_2CO_3$, decomposes, when heated, into NH_3 and CO_2 and H_2O, all of which are simpler compounds. When an organic substance like blood or meat or cottonseed-meal decomposes, the organic compounds in them, which are very complex, form simpler compounds, generally the same as in case of ammonium carbonate or others equally simple. The terms simple and complex are, of course, relative; for example, HNO_3 is complex compared with HCl, but simple compared with $Ca_3(PO_4)_2$.

CHAPTER IV

SOURCES AND COMPOUNDS OF PLANT-FOOD ELEMENTS

In this chapter we shall take up those elements which have a special interest for us, stating briefly their most common sources, and discussing the composition and properties of some of their more important compounds. Information regarding the special materials in which the compounds occur in commercial forms is reserved for Part II (pp. 244-287). The special practical applications in respect to selection and purchase and use in the growing of crops will be studied in detail in Parts III and IV (pp. 397-710).

NITROGEN

Sources of nitrogen.—Nitrogen occurs in nature chiefly in the following forms: (1) Atmospheric nitrogen, (2) ammonia, (3) in animal and vegetable matter, and (4) as nitrate. It has been a common custom to speak of nitrogen in different forms as ammonia, a term which should never be applied to nitrogen in any form except that of ammonia or ammonium compounds. To speak of organic nitrogen or nitrate nitrogen as ammonia is inaccurate and often wholly misleading.

(1) *Atmospheric nitrogen.*—Nitrogen in the free or uncombined form constitutes about four-fifths of the air, an amount equal to many thousands of tons for each acre on the surface of the earth. Nitrogen cannot be used directly from the air by crops; but certain plants belonging to the leguminous or so-called bean family are able to use it indirectly through the medium of certain microorganisms growing on the roots of the plants (p. 216).

(2) *Nitrogen in ammonia.*—Ammonia (NH_3) is a compound containing 14 parts by weight of nitrogen combined with 3 parts by weight of hydrogen. It is a colorless gas and dissolves easily in water, forming the familiar compound called spirits of hartshorn or ammonia water, which in its strong form contains 28 per cent. of ammonia and which has the composition shown by the symbol NH_4OH. Ammonia is present in the air in very small amounts, being produced when vegetable or animal substances undergo decomposition (p. 198); it is often present in horse stables and in fermenting manure heaps in amounts sufficient to produce the pungent odor characteristic of ammonia.

The leaves of some plants have the power of absorbing ammonia directly from the air, and obtain nitrogen as food in this way, but only in very small amounts. Some plants utilize nitrogen directly from ammonium compounds in the soil, but in general the nitrogen of ammonia and its compounds is changed into the form of nitrate in the soil before its nitrogen reaches plants (p. 204).

(3) *Nitrogen in animal and vegetable matter, or organic nitrogen.*—Nitrogen in combination with the elements, hydrogen, carbon, oxygen, and sometimes with sulphur and phosphorus, occurs in animals and plants in a great variety of different compounds, known under the general name of *proteins* (p. 19). In such combinations the nitrogen is called *organic* nitrogen. The nitrogen in slaughter-house by-products, such as blood, meat, tankage, etc., is organic; also in fish, bone, cottonseed-meal, tobacco stems, green-crop manures, the solid portion of animal manures, etc. Before the nitrogen in such compounds can be used as food by plants, the substances, through the action of micro-organisms (p. 203), must undergo decay, forming a large number of simpler compounds, and being changed sooner or later into ammonia

and finally into nitrate nitrogen under proper conditions of warmth, moisture, etc. (p. 204).

(4) *Nitrogen in nitrate.*—We have already seen (p. 30) that nitrogen combines with hydrogen and oxygen to form nitric acid (HNO_3), which contains 22.2 per cent. of nitrogen, 76.2 per cent. of oxygen and 1.6 per cent. of hydrogen. An old name for nitric acid is *aqua fortis* (strong water). Nitric acid combines with metals to form nitrates (p. 31), such, for example, as sodium nitrate, $NaNO_3$, (p. 27) calcium nitrate, $Ca(NO_3)_2$ (p. 41), etc. We can conveniently speak of nitrogen in the form of nitric acid or nitrates as *nitrate nitrogen.* In the soil nitrate nitrogen is formed from organic nitrogen and ammonia through a process known under the general name of *nitrification* (p. 204). Most of the nitrogen used by plants as food is in the form of nitrate nitrogen; this is the most quickly available source of nitrogen in plant nutrition.

Compounds of nitrogen.—Compounds, containing nitrogen in available form and useful in the growing of crops, include the following as the most important: (1) Nitrates of sodium, potassium, calcium and magnesium; (2) ammonium compounds, the sulphate, nitrate and carbonate; (3) calcium cyanamid. Most of these compounds in their commercial forms are discussed in detail on pages 244-253. We shall consider here, for the most part, only their composition and a few chemical characteristics.

(1) *Sodium nitrate,* $NaNO_3$, known in its commercial form as nitrate of soda (p. 244), contains 16.47 per cent. of nitrogen. It is very easily soluble in water, one pound of the salt dissolving in about one pint of water under ordinary conditions. It has for some years been the chief nitrogen-containing constituent used in many commercial fertilizers.

When sodium nitrate is treated with strong sulphuric

acid, the nitric acid may be lost as a gas, since it is set free in the manner represented in the following chemical reaction, in which the figures over each symbol stand for the weight used.

$$\underset{\text{Sodium nitrate}}{\overset{170}{2NaNO_3}} + \underset{\text{Sulphuric acid}}{\overset{98}{H_2SO_4}} = \underset{\text{Nitric acid}}{\overset{126}{2HNO_3}} + \underset{\text{Sodium Sulphate}}{\overset{142}{Na_2SO_4}}$$

This fact has a practical bearing, since sulphuric acid should never be mixed with a nitrate. This may happen when a poorly made acid phosphate, in which too much sulphuric acid has been used or the operation of mixing improperly managed, is mixed with sodium nitrate.

In moist air sodium nitrate absorbs moisture and tends to become liquid.

(2) *Potassium nitrate,* KNO_3, known in commercial form as *niter* or *saltpeter* (p. 252), contains 13.85 per cent. of nitrogen. It is quickly soluble and is available as plant-food for both nitrate and potassium. One pound of the salt dissolves in about three pints of water.

(3) *Calcium nitrate,* $Ca(NO_3)_2$, known in its commercial form as *lime nitrate* (p. 249), contains 17 per cent. of nitrogen. It is very easily soluble in water. It has so strong an attraction for water that, when in contact with moist air, it tends to absorb so much moisture as to become liquid.

(4) *Ammonium sulphate,* $(NH_4)_2SO_4$, called *sulphate of ammonia* in its commercial form (p. 246), contains 21.2 per cent. of nitrogen, which is equal to 25.75 per cent. of ammonia (NH_3). One pound of the salt dissolves in about 1 1-3 pints of water. It does not absorb moisture from the air, as the nitrate of sodium or of calcium does.

(5) *Ammonium nitrate,* NH_4NO_3, is the most concentrated nitrogen compound that is employed as plant-food, containing 35 per cent. of nitrogen, one-half as ammonia (NH_3) nitrogen, and one-half as nitrate (NO_3) nitrogen. As we shall see later, this combination gives it

special value. Its price is so high that it has been used very little in general agriculture. It is one of the most easily soluble compounds, one pint of water dissolving two pounds of the salt.

(6) *Ammonium carbonate*, $(NH_4)_2CO_3$, contains nearly 29.2 per cent. of nitrogen. It is easily soluble in water, one pound dissolving in three or four pints of water. It is rarely, if ever, used in commercial fertilizers, but is of interest because it is found in the decomposition of animal and vegetable matter, especially of urine. This compound is one which breaks up or decomposes very easily, forming ammonia gas (NH_3), carbon dioxide gas (CO_2) and water (H_2O); this action takes place more rapidly at temperatures above 100°F. When urine, especially of horses, ferments, ammonium carbonate is formed, and in a warm stable or manure pile, the ammonia gas escapes into the air, producing a more or less strong, characteristic ammonia smell.

(7) *Calcium cyanamid*, $CaCN_2$, commercially known as *lime nitrogen* (p. 247) contains 35 per cent. of nitrogen when pure. It is one of the most recent compounds introduced into commercial fertilizers.

PHOSPHORUS

Source of phosphorus.—The original source of all phosphorus compounds is the earth's crust. As immediate sources of supply for plant-food uses we have (1) the soil, (2) the large phosphate deposits and (3) bones of animals.

Compounds of phosphorus.—Phosphorus is always found in nature in combination with other elements and usually in the form of phosphates, which are combinations of phosphoric acid (H_3PO_4 or $-PO_4$) with metals (p. 34), especially calcium. The form in which phosphorus is generally found in animals and plants is calcium phosphate, with small amounts of magnesium,

sodium and potassium phosphates. In the soil we have, in addition, iron and aluminum phosphates. Calcium forms several different compounds with phosphoric acid, commonly known as phosphates of lime, all of which are important as sources of plant-food phosphorus.

Use of terms, phosphoric acid and phosphates. Before considering the phosphates farther, we wish to call attention to the use of the term, phosphoric acid, as commonly applied in connection with fertilizers, when it always means a compound whose composition is expressed by the symbol P_2O_5, which contains 43.7 per cent. of phosphorus. How this usage came about we need not take time to detail farther than to say that it is a survival of a custom established long ago by chemists for expressing results of analysis; and for the sake of uniformity this old usage has persisted, especially in commercial applications. When we say that a compound or a fertilizer contains, for example, 10 per cent. of phosphoric acid (P_2O_5), we mean the same thing as when we say that it contains 4.4 per cent. of phosphorus (P). On many accounts it would be preferable to state the percentages as phosphorus (P) rather than as P_2O_5; but the present usage has become so firmly established that many practical difficulties would be encountered in making the change. Such a change in connection with fertilizers has, however, been under discussion by agricultural chemists for some years and will probably be brought about gradually in time. In our discussions, we shall usually state amounts in both forms, viz. as phosphoric acid (P_2O_5) and as phosphorus (P). The terms phosphate, phosphorus and phosphoric acid compounds, will be used often in speaking of these compounds when they are referred to without reference to any special percentage composition. In this connection we will refer to a clearly wrong use of the word phosphate, which is all but universal among farmers using commercial fertilizers; and

that is the application of the word phosphate as a general term covering all kinds of commercial fertilizers, whether they contain phosphoric acid compounds only, or mixtures of these with nitrogen and potassium compounds, or even when commercial mixtures contain no phosphorus compounds at all.

Phosphoric acid compounds or phosphates.—The existence of four phosphate compounds of calcium is recognized; the composition of three of these has already been referred to (p. 36) and certain relations pointed out. These four compounds differ in their composition mainly in respect to the amount of calcium they contain, since calcium is present in the ratio of one, two, three and four parts *or combining weights* (p. 23). The fourth compound is quite different from the three others in respect to its source and is not so closely related to them as they are to each other. We shall, therefore, consider the one, two and three calcium phosphates together. These compounds are known under an unusual variety of names, which may easily lead to confusion, but they can readily be kept distinct by knowing their individual characteristics with reference to one important property, viz., *their solubility in water.* For convenience, we will, therefore, distinguish these three calcium phosphates primarily by the following names: *Soluble, reverted* and *insoluble;* these terms are the ones most commonly used in studying the composition of phosphatic materials. The tabulated arrangement given below shows the following facts with reference to each of the three phosphates: (1) Different names, (2) chemical composition as expressed by formula, both new and old forms, (3) percentage of phosphorus and (4) its equivalent in the form of P_2O_5.

TABLE 6—NAMES AND COMPOSITION OF CALCIUM PHOSPHATE COMPOUNDS

Names	Chemical Symbols	Percentage of phosphorus (P)	Percentage of phosphoric acid (P_2O_5)
(1) SOLUBLE CALCIUM PHOSPHATE Mono- (or 1-) calcium phosphate Monobasic phosphate Primary calcium phosphate Calcium acid phosphate Acid calcium phosphate Acid phosphate of lime Acid phosphate Soluble phosphoric acid Soluble phosphate of lime, etc.	New form: $CaH_4(PO_4)_2$, or Old form: $(CaO)(H_2O)_2$, P_2O_5	26.5	60.7
(2) REVERTED CALCIUM PHOSPHATE Di- (or 2-) calcium phosphate Dibasic phosphate Secondary calcium phosphate Citrate-soluble phosphate Reverted phosphoric acid Reverted phosphate of lime Precipitated phosphate of lime, etc.	New form: $Ca_2H_2(PO_4)_2$, or Old form: $(CaO)_2$, H_2O, P_2O_5	22.8	52.2
(3) INSOLUBLE CALCIUM PHOSPHATE Tri- (or 3-) calcium phosphate Tribasic phosphate Calcium phosphate Normal calcium phosphate Insoluble phosphate of lime Insoluble phosphoric acid Bone phosphate of lime, etc.	New form: $Ca_3(PO_4)_2$, or Old form: $(CaO)_3$, P_2O_5	20.0	45.8
(4) TETRA-CALCIUM PHOSPHATE Tetra-basic calcium phosphate Tetra-basic phosphate of lime Thomas phosphate powder Basic-slag phosphate Basic-slag phosphate of lime, etc.	New form: $Ca_4P_2O_9$, or Old form, $(CaO)_4$, P_2O_5	17.0	39.0

The prominent points to remember in connection with the preceding table are (1st) that the calcium in these compounds is in the relation of one, two, three and four; and (2d) that the proportion of phosphoric acid or phosphorus is greatest in the compound containing least calcium and decreases in the other compounds as the calcium increases.

Before going into the special characteristics of these compounds, we will first consider some particular rela-

tions existing between the insoluble, reverted and soluble forms of calcium phosphate. Briefly stated, the insoluble can be converted into the reverted form by treatment with a certain amount of acid and into the soluble form by the use of twice as much acid. The soluble can be changed into the reverted form by certain compounds.

In the commercial manufacture of "superphosphate of lime" (p. 271), sulphuric acid is used to dissolve the insoluble phosphate. We will now give in the form of equations the action of sulphuric acid upon insoluble calcium phosphate when different amounts of acid are used. The figures over each symbol give the amount of each compound used in the reaction.

(a) Formation of reverted from insoluble phosphate:

310		98		272		136
$Ca_3(PO_4)_2$	+	H_2SO_4	=	$Ca_2H_2(PO_4)_2$	+	$CaSO_4$
Insoluble calcium phosphate		Sulphuric acid		Reverted calcium phosphate		Calcium sulphate (or gypsum)

(b) Formation of soluble from reverted phosphate:

272		98		234		136
$Ca_2H_2(PO_4)_2$	+	H_2SO_4	=	$CaH_4(PO_4)_2$	+	$CaSO_4$
Reverted calcium phosphate		Sulphuric acid		Soluble calcium phosphate		Calcium sulphate (or gypsum)

(c) Formation of soluble directly from insoluble without any reverted phosphate, showing the two preceding changes in one:

310		196		234		272
$Ca_3(PO_4)_2$	+	$2H_2SO_4$	=	$CaH_4(PO_4)_2$	+	$2CaSO_4$
Insoluble calcium phosphate		Sulphuric acid		Soluble calcium phosphate		Calcium sulphate (or gypsum)

In actual commercial operations, water is present and, instead of $CaSO_4$ (water-free calcium sulphate), there is formed $CaSO_4.2H_2O$, which is gypsum, or hydrated calcium sulphate.

The formation of reverted from soluble calcium phosphate will be considered later under the head of reverted calcium phosphate.

(1) *Insoluble calcium phosphate* is contained in varying amounts in all agricultural soils, in animal and vegetable matter, especially in bones and seeds, in many mineral deposits and in water that has been in contact with soils. The commercial materials in which this compound occurs are considered in detail later (pp. 261-271).

This form of calcium phosphate is called insoluble because it does not easily dissolve in water, one part requiring for solution 50,000 parts of pure water, more or less, according to certain conditions. Its solubility in water is made greater by the presence of some substances and less by others. Water containing carbon dioxide (p. 60), as in the case of soil water, dissolves much more insoluble phosphate than does pure water. Some of the compounds used in fertilizers increase the solubility of this phosphate in water, among which are sodium nitrate, ammonium sulphate, and potassium sulphate. Gypsum and iron compounds make it less soluble in water. Substances which appear to have little influence are magnesium sulphate and chloride, sodium chloride (common salt) and potassium chloride (muriate).

(2) *Soluble calcium phosphate* is the principal constituent in the commercial product known as *"superphosphate of lime"* (p. 271), which is more extensively used in fertilizers than any other compound. It is never found occurring naturally, but is a manufactured product. The special importance of this compound is due to its solubility in water, one part dissolving completely in 100 parts of water under ordinary conditions, but it is easily changed by certain other compounds into the reverted form. On account of its ready solubility, it is the compound that is most extensively used by plants as the source of their phosphorus.

(3) *Reverted calcium phosphate* receives its name from the fact that it can be formed from soluble calcium phosphate and is less soluble in water, so that, when solu-

ble phosphate is changed into this form, it is said to "revert" or go back to an insoluble or less soluble condition. Reverted phosphate is, however, much more readily soluble in water containing carbon dioxide than in pure water. One part of reverted phosphate requires for its solution about 7,500 parts of pure water, but only about 1,800 parts of water containing carbon dioxide. It is thus seen that this compound is fairly soluble in soil water. Among the names by which reverted phosphate is known is that of "citrate-soluble," which comes from the fact that, in ascertaining the amount of reverted phosphate by chemical analysis, it is dissolved in a solution of ammonium citrate.

We have already seen that reverted phosphate is formed when the insoluble compound is treated with a limited amount of sulphuric acid. It is formed also from soluble calcium phosphate by such compounds as the insoluble phosphate, calcium carbonate, etc., as shown by the following reactions:

(a) Formation of reverted by insoluble phosphate:

$$\begin{array}{ccccc} 234 & & 310 & & 544 \\ CaH_4(PO_4)_2 & + & Ca_3(PO_4)_2 & = & 2Ca_2H_2(PO_4)_2 \\ \text{Soluble calcium} & & \text{Insoluble calcium} & & \text{Reverted calcium} \\ \text{phosphate} & & \text{phosphate} & & \text{phosphate} \end{array}$$

This action occurs in a superphosphate on standing, when the insoluble phosphate has not been completely dissolved by acid.

(b) Formation of reverted phosphate by calcium carbonate:

$$\begin{array}{ccccccccc} 234 & & 100 & & 272 & & 44 & & 18 \\ CaH_4(PO_4)_2 & + & CaCO_3 & = & Ca_2H_2(PO_4)_2 & + & CO_2 & + & H_2O \\ \text{Soluble calcium} & & \text{Calcium} & & \text{Reverted calcium} & & \text{Carbon} & & \text{Water} \\ \text{phosphate} & & \text{carbonate} & & \text{phosphate} & & \text{dioxide} & & \end{array}$$

In the presence of large amounts of calcium carbonate or of hydroxide (slaked lime), the soluble and reverted may be changed completely to insoluble calcium phosphate.

(c) Formation of insoluble from soluble phosphate by calcium carbonate:

$$\underset{\substack{\text{Soluble calcium}\\ \text{phosphate}}}{\overset{234}{CaH_4(PO_4)_2}} + \underset{\substack{\text{Calcium}\\ \text{carbonate}}}{\overset{200}{2CaCO_3}} = \underset{\substack{\text{Insoluble calcium}\\ \text{phosphate}}}{\overset{310}{Ca_3(PO_4)_2}} + \underset{\substack{\text{Carbon}\\ \text{dioxide}}}{\overset{88}{2CO_2}} + \underset{\text{Water}}{\overset{36}{2H_2O}}$$

(3) *Tetra calcium phosphate,* $Ca_4P_2O_9$, or $(CaO)_4$, P_2O_5, is a manufactured by-product. It is commonly known as basic-slag phosphate and will be considered in more detail on page 275.

(4) *Magnesium phosphates* are much like those of calcium in their general properties.

(5) *Iron phosphate,* $FePO_4$, *and aluminum phosphate,* $AlPO_4$, are noted for their insolubility in water. When iron or aluminum compounds, such as oxides, are present in large amounts in soils, they may act upon any soluble calcium phosphate that is applied and convert it into the very insoluble phosphate of iron or aluminum, practically causing the complete loss of the soluble phosphate for immediate crop uses. This loss can be prevented by keeping in the soil an abundance of calcium carbonate (p. 374). These insoluble phosphates are changed by calcium carbonate into insoluble calcium phosphate, which is more readily available.

We have now completed our study of the different phosphate compounds so far as their special properties are concerned. Some of them are among our most important commercial products, of which we shall make a study later (p. 261).

POTASSIUM

Experiments have shown that when potassium compounds are lacking, plants suffer severely, though they may not die. Potassium forms a larger part of the ash of plants than any other mineral element. On an average, vegetable ash consists of about one-third potassium.

Source of potassium.—The element potassium is never found in nature uncombined; it always exists in compounds. It is a constituent of many minerals. The partial solution and decomposition of the rocks containing these minerals give rise to the presence of potassium compounds everywhere in the soil, which are taken up by plants and used as food. When vegetable material is burned, the potassium forms a part of the unburned ash, in which it is present as potassium carbonate, K_2CO_3. When wood-ashes are treated with water and leached, the potassium carbonate along with some other compounds is dissolved, forming "lye"; and this evaporated to dryness leaves impure potassium carbonate, which was years ago an article of commerce known as *pot-ash* on account of being made in iron pots. In this way came the word, *potassium*, the Latin form of which is Kalium; and K, the first letter of the Latin word, is therefore used as the chemical symbol of potassium. The word *potash* is almost universally used in agricultural literature in referring to potassium compounds. In the analysis of potassium compounds, it became the custom a long time ago to give the results of analysis not as potassium (K) but as potassium oxide (K_2O), which was called potash. This custom has unfortunately persisted to the present time; and when we analyze a fertilizer for potassium, we do not often state the result as potassium (K) but as potash (K_2O). On many accounts it would be desirable if we could abolish the use of the word potash in analytical and agricultural chemistry and use only potassium, but commercial custom is slow to change. It is wholly incorrect to say that potassium chloride, for example, contains 50 per cent. of potash (K_2O), since it contains no oxygen at all. Of course, under such circumstances it simply means that the amount of potassium (K) in the compound is equivalent to 50 per cent. of K_2O. Another expression, *actual* potash, is also used in fertilizer analy-

sis to express K_2O. In stating amounts, we shall commonly make use of both forms K_2O and K.

Compounds of potassium.—In this place we shall give some of the chief characteristics of a few potassium compounds that are of interest as valuable plant-foods. Their commercial forms, as used in making fertilizers, we shall describe in detail later (p. 278). We shall notice five potassium compounds: Carbonate, chloride, sulphate nitrate and silicates.

(1) *Potassium carbonate,* K_2CO_3, known also as carbonate of potash, contains 56.6 per cent. of potassium, which is equivalent to 68 per cent. of potash (K_2O). It is strongly alkaline (p. 28). It is very easily soluble in water, two pints of water dissolving one pound of carbonate. The only form of carbonate once used in the feeding of plants was that contained in wood-ashes (p. 283).

(2) *Potassium chloride,* KCl, known commonly in commercial forms as muriate of potash, contains 52.5 per cent. of potassium, which is equivalent to 63.2 per cent. of potash. It is easily soluble in water, three pints of water dissolving one pound of the chloride. It closely resembles common salt in appearance and taste. It is a valuable source of plant-food (p. 279) and is more extensively used in fertilizers than any other potassium compound.

(3) *Potassium sulphate,* K_2SO_4, known commercially as sulphate of potash, contains 45 per cent. of potassium, which is equivalent to 54 per cent. of K_2O. While it is quite easily soluble in water, it is less so than the carbonate or chloride, one pound of sulphate requiring eight to ten pints of water for solution. This compound has special value as a source of potassium, since it must be used with some crops which are injured by the chloride (p. 700).

(4) *Potassium nitrate,* KNO_3, known commercially as nitrate of potash, niter, and saltpeter, contains 38.6 per cent. of potassium, which is equivalent to 46.6 per cent. of potash. It is about as easily soluble in water as the chloride. This compound possesses additional value as plant-food on account of its being in the nitrate form. Unfortunately, it is used so extensively in the manufacture of gunpowder that it is too expensive to use on crops.

(5) *Silicates.*—Potassium is present in several different mineral compounds in combination with oxygen, silicon, aluminum and other metals, among which are (a) orthoclase or potassium feldspar (K_2O, Al_2O_3, $6SiO_2$); (b) leucite (K_2O, Al_2O_3, $4SiO_2$); (c) micas, zeolites and glauconite, which are very complex silicates, containing several different metals in union as silicates.

CALCIUM

The element calcium is essential to the development of plants. Its compounds are commonly called *lime* compounds, as the result of a former usage by chemists. The term *lime* should properly be used only when speaking of the compound calcium oxide, CaO, and we shall generally use the word calcium in speaking of so-called lime compounds.

Source.—Calcium, like the other mineral elements, has its source in the crust of the earth, where it occurs in a variety of compounds, especially the carbonate.

Compounds of calcium.—Some of its compounds are among the most useful in agriculture, among which are the carbonate, the oxide, hydroxide, phosphates, nitrate, and, in a less degree, the sulphate. The calcium compounds will be more fully discussed in connection with indirect fertilizers (p. 363). In this place we shall consider certain chemical relations of the following compounds: (1) Calcium carbonate, (2) calcium oxide, (3)

calcium hydroxide, (4) calcium phosphates, (5) calcium nitrate, (6) calcium sulphate, and (7) calcium silicate.

(1) *Calcium carbonate,* $CaCO_3$, known in commerce as *carbonate of lime, ground limestone,* etc. (p. 369), contains 40 per cent. of calcium, which is equivalent to 56 per cent. of lime (CaO). The carbonate is the chief constituent of limestone, marble, chalk, shell-marl, coral, shells, etc. Calcium carbonate is only slightly soluble in pure water, but in water containing all the carbon dioxide it can hold at ordinary temperatures, the carbonate is soluble to the extent of one pound in 1,000 pints of water. Calcium carbonate has basic (p. 30) properties, neutralizing acids and forming salts, as illustrated by the following reaction:

$$\begin{array}{ccccccccc} 100 & & 126 & & 164 & & 44 & & 18 \\ CaCO_3 & + & 2HNO_3 & = & Ca(NO_3)_2 & + & CO_2 & + & H_2O \\ \text{Calcium} & & \text{Nitric} & & \text{Calcium} & & \text{Carbon} & & \text{Water} \\ \text{carbonate} & & \text{acid} & & \text{nitrate} & & \text{dioxide} & & \end{array}$$

This reaction takes place in the soil when nitric acid is formed (p. 205).

(2) *Calcium oxide,* CaO, commercially known as *quick-lime, burnt lime, caustic lime, stone-lime, lump-lime, building-lime,* etc. (p. 365), contains 71.4 per cent. of calcium. It is made by burning calcium carbonate, the carbon dioxide being driven off. The chemical change is shown by the following equation:

$$\begin{array}{ccccccc} 100 & & & & 56 & & 44 \\ CaCO_3 & + & \text{heat} & = & CaO & + & CO_2 \\ \text{Calcium} & & & & \text{Calcium} & & \text{Carbon} \\ \text{carbonate} & & & & \text{oxide} & & \text{dioxide} \end{array}$$

This shows that when we burn 100 pounds of pure calcium carbonate, we obtain 56 pounds of calcium oxide, 44 pounds of carbon dioxide gas going into the air. Calcium oxide has basic properties (p. 29), neutralizing acids and forming salts, as illustrated by the following reaction:

$$\begin{array}{ccccccc} 56 & & 126 & & 164 & & 18 \\ CaO & + & 2HNO_3 & = & Ca(NO_3)_2 & + & H_2O \\ \text{Calcium} & & \text{Nitric} & & \text{Calcium} & & \text{Water} \\ \text{oxide} & & \text{acid} & & \text{nitrate} & & \end{array}$$

This reaction occurs in the manufacture of lime nitrate (p. 249).

(3) *Calcium hydroxide,* CaH_2O_2, commonly called *slaked lime, hydrated lime, caustic lime,* etc. (p. 367), contains 54 per cent. of calcium, which is equal to 75.7 per cent. of CaO. One pound of calcium hydroxide is soluble in 800 to 1,000 pints of water, the solution being known as *lime-water.* Calcium hydroxide is formed when calcium oxide is treated with water; it then undergoes the change known as *slaking* (or slacking), according to the following chemical reaction:

$$\begin{array}{ccccc} 56 & & 18 & & 74 \\ CaO & + & H_2O & = & CaH_2O_2 \\ \text{Calcium} & & \text{Water} & & \text{Calcium hydroxide} \\ \text{oxide} & & & & \text{(slaked lime)} \end{array}$$

Slaked lime may therefore be properly regarded as quicklime (CaO) diluted with about one-third of its weight of water, except that the water is not merely mixed, but is chemically combined, with the lime.

Air-slaked lime is calcium oxide that has absorbed moisture from the air and changed into hydroxide. The operation is slow, depending largely on the amount of moisture in the air. As the slaked lime is formed it slowly absorbs carbon dioxide from the air, forming carbonate, as shown by the following reaction:

$$\begin{array}{ccccccc} 74 & & 44 & & 100 & & 18 \\ CaH_2O_2 & + & CO_2 & = & CaCO_3 & + & H_2O \\ \text{Calcium hydroxide} & & \text{Carbon} & & \text{Calcium} & & \text{Water} \\ \text{or slaked lime} & & \text{dioxide} & & \text{carbonate} & & \end{array}$$

Air-slaked lime is, therefore, generally a mixture of hydroxide and carbonate; but in case of long exposure the change to carbonate becomes complete. Air-slaked lime is thus seen to be of very uncertain composition, since it may vary anywhere from nearly pure hydroxide to nearly pure carbonate.

Calcium hydroxide is an alkaline base (p. 29), changing red litmus to blue. It is therefore useful in neutralizing acids. It is also somewhat powerful in promoting

disintegration of animal or vegetable matter, for which reason it is called *caustic.*

(4) *Calcium phosphates* (p. 45).

(5) *Calcium nitrate* (p. 41).

(6) *Calcium sulphate,* $CaSO_4$, known in commerce under various names, as *gypsum, land-plaster sulphate of lime, plaster of Paris,* etc., contains 29.4 per cent. of calcium, which is equal to 41.2 per cent. of CaO. It should be stated that gypsum contains about 21 per cent. water as expressed by the formula, $CaSO_4.2H_2O$. When this is heated at 212°F., just enough to drive off the water, the resulting product, $CaSO_4$, free from water, forms a powder, which is called plaster of Paris; this takes water up readily, again forming $CaSO_4.2H_2O$, which has the property of hardening quickly or "setting." In the form of gypsum, calcium sulphate has been used in agriculture quite extensively in the past. When used in stables mixed with manure, it combines with ammonium carbonate, forming ammonium sulphate and calcium carbonate, as shown in the following reaction:

$$\underset{\substack{\text{Calcium}\\\text{sulphate}}}{\overset{136}{CaSO_4}} + \underset{\substack{\text{Ammonium}\\\text{carbonate}}}{\overset{96}{(NH_4)_2CO_3}} = \underset{\substack{\text{Ammonium}\\\text{sulphate}}}{\overset{132}{(NH_4)_2SO_4}} + \underset{\substack{\text{Calcium}\\\text{carbonate}}}{\overset{100}{CaCO_3}}$$

Calcium sulphate in the form of gypsum ($CaSO_4.2H_2O$) is soluble, one pound in about 400 pints of water.

MAGNESIUM

In chemical behavior, magnesium and its compounds resemble calcium in many ways. It is not common that magnesium compounds are applied specially in agriculture for fertilizing purposes.

Source.—Magnesium compounds are present in all agricultural soils, the amounts varying in different soils. Magnesium often occurs along with calcium as carbonate

in so-called dolomitic limestone. One source of commercial supply is the German potash mines (p. 278).

Compounds of magnesium.—The most familiar compounds of magnesium are the oxide, hydroxide, carbonate, chloride, nitrate, phosphates, sulphate and silicates, some of which we will notice in brief.

(1) *Magnesium oxide*, MgO, commercially known as *calcined magnesia*, is best known as a constituent of burnt lime prepared from magnesium limestone, in which it occurs in amounts varying from approximately 10 per cent. up to 40 per cent. or more. Its presence in large amounts is objectionable for many purposes, since it slakes much more slowly than calcium oxide.

(2) *Magnesium hydroxide*, MgH_2O_2, is formed by treating magnesium oxide with water. This compound, unlike calcium hydroxide, is only slightly soluble in water. It is present, of course, in slaked magnesium lime.

(3) *Magnesium sulphate*, $MgSO_4$, known commonly as *Epsom salt*, is contained in some of the German potash salts (p. 280), in which likewise magnesium chloride, $MgCl_2$, is found.

(4) *Magnesium silicates.*—The minerals, serpentine and talc, are hydrated silicates of magnesium, varying in their percentage of water. Magnesium occurs also in some of the complex silicates.

SULPHUR

Though present in plants in only small amounts, sulphur compounds are always found and are essential. They are usually present in soils in sufficient abundance to meet agricultural demands.

Source.—Sulphur is found in a great many minerals in which it is in combination with other elements. Under the usual conditions of soil formation, all forms of sulphur compounds are sooner or later changed into sul-

phates, which are salts of sulphuric acid (p. 31), and this is the only form in which agricultural plants utilize sulphur obtained from the soil.

Compounds of sulphur.—The sulphur compounds which are found in soils and some of which are present in fertilizers in combination with other essential constituents are the following, most of which have been already considered in connection with other elements: (1) Potassium sulphate (p. 51), (2) calcium sulphate (p. 55), (3) sodium sulphate (p. 34), (4) magnesium sulphate (p. 56), (5) ammonium sulphate (p. 41). The sulphur in these compounds varies from 18 to 26 per cent.

Sodium sulphate, Na_2SO_4, known also as Glauber's salt and sulphate of soda, is found in soils of dry regions, being a prominent constituent of "white alkali" and "alkali dust"; it is an undesirable constituent, since it is a plant poison when present beyond certain limits; it is, however, less poisonous to plants than common salt.

Ferrous or iron sulphate, $FeSO_4$, commonly called green-vitriol or copperas, may be briefly referred to in passing. It is sometimes found in considerable amounts in soils that have been under water and then drained and brought under cultivation. It is a plant poison when present beyond certain amounts. Such soils bear poor crops until, by treatment with generous amounts of calcium carbonate and thorough cultivation, the iron sulphate is changed into harmless forms of combination. It has been sometimes applied to soils as an indirect fertilizer (p. 392).

IRON

Though used in smaller amount than any other plant-food constituent, iron compounds are essential to the growth of plants. This element does not, however, have much interest for us in connection with the use of fer-

tilizers, because all agricultural soils possess an unlimited abundance and need no additions, so far as we know at present.

Source.—There are numerous minerals containing iron which have furnished the supply now in our soils. Iron compounds impart characteristic colors to soils (p. 111).

Compounds of iron.—The form in which iron is most commonly found in soils is in combination with oxygen and hydrogen either as *iron (ferric) oxide*, Fe_2O_3, or as *hydroxide*, FeH_3O_3, or some similar form of combination, known as hydrated oxides, of which there are many forms of indefinite composition. These compounds are reddish brown or yellow in color; they have practically the same composition as iron rust. Whatever kind of compound iron in the soil may originally exist in, it is sooner or later changed into one of the forms mentioned. Iron (ferrous) sulphate has already been mentioned in connection with sulphates. The iron compounds commonly present are only slightly soluble in water, but sufficiently so to furnish all that is needed by plants. Iron compounds in solution change soluble calcium phosphate into the very insoluble iron phosphate, unless the soil contains an abundance of calcium carbonate.

CHLORINE

Source.—Chlorine is always found in soils and plants, but only in the form of compounds. Larger amounts are present in sea water and in special deposits in the earth.

Compounds of chlorine.—In combination with hydrogen, chlorine forms hydrochloric (or muriatic) acid (HCl), and in combination with metals it forms salts which are called chlorides (p. 32). The most familiar compounds are (1) potassium chloride (p. 51), (2) sodium chloride, (3) magnesium chloride (p. 56).

Sodium chloride, $NaCl$, familiar under the name of

common salt, contains 60.7 per cent. of chlorine and 39.3 per cent. of sodium. Its ready solubility in water is a familiar fact of everyday experience. *Agricultural salt* is an impure form of sodium chloride. Its agricultural importance is not great. When used at all, it is as an indirect fertilizer (p. 391). Salt is generally a constituent of the alkali soils of dry regions.

SODIUM

Source.—Inasmuch as sodium generally occurs in soils as sodium chloride, its origin and relations are essentially the same as those of chlorine.

Compounds of sodium.—The most abundant compound of sodium is the *chloride*. As stated under sulphur compounds, *sodium* sulphate is the chief constituent of the "white alkali" of arid regions. *Sodium carbonate* is a constituent of the "black alkali" spots in soils of arid regions, the dark color being due to the action of the alkali on the organic matter of the soil. The most important agricultural compound of sodium is the nitrate (p. 244), the value of which is, however, due to the nitrogen.

SILICON

Source.—Next to oxygen silicon is the most abundant element in the earth's crust and, therefore, in soils. It is a constituent of many of the most common rocks. It is of more interest agriculturally for its relations to the soil than to plant nutrition directly.

Compounds.—Silicon is found in a number of different compounds; we shall notice only two kinds, (1) silicon dioxide and (2) silicates.

(1) *Silicon dioxide*, SiO_2, commonly known as *silica*, is prevalent in rocks and soils in the familiar form of *quartz*. It contains about 47 per cent. of silicon. It is the chief constituent of sand.

(2) *Silicates.*—There are many compounds in this class, some of which are very complex, containing several different metals in combination with some form of silicic acid. The simplest forms are represented by potassium and sodium silicates (K_2SiO_3, Na_2SiO_3), which dissolve in water and are then known as water-glass. Common feldspar contains potassium or sodium or calcium in combination with aluminum and silicic acid, as, for example, $AlKSi_3O_8$, $AlNaSi_3O_8$, etc. Pure clay is aluminum silicate combined with water, known as hydrated aluminum silicate.

CARBON

Source.—The source of supply of carbon as plant-food is the carbon dioxide of the air. While we are interested in carbon as it is found in combination in organic forms and in the form of carbonates (p. 34), our main interest in connection with plant nutrition is limited to the atmospheric compound.

Compounds of carbon.—While the number of compounds of carbon is innumerable, we need for our purposes consider only one.

Carbon dioxide, CO_2, commonly known as *carbonic acid gas,* is a compound containing 27.3 per cent. of carbon and 72.7 per cent of oxygen. It is present in the air under ordinary conditions to the extent of about 3 parts in 10,000 of air. Though present in so small proportions, we have in the atmosphere resting upon one acre of ground more than 28 tons of this gas, containing over 7½ tons of carbon, an amount sufficient to supply many times the amount of carbon any crop can possibly use. To furnish the carbon in a tree containing 10,000 pounds of dry matter would require about 15,000,000 cubic yards of air. There is, however, no danger that the carbon dioxide of the air will ever be appreciably reduced

in amount, because the supply is being constantly replenished in various ways, as by the burning of fuel, the breath of animals and all natural processes of decay of organic matter. Thus, one ton of good coal produces, in burning, over 3 tons of carbon dioxide gas. The people in a town of 10,000 inhabitants daily breathe out not less than 5 tons of this gas, an amount that would furnish enough carbon to grow several acres of any large-yielding crop.

OXYGEN

Oxygen is the most abundant of all the chemical elements, forming a large part of earth, air and water. It occurs naturally in both combined and uncombined forms.

Source of oxygen.—For convenience, we can consider under four divisions the forms in which oxygen exists: (1) Atmospheric oxygen, (2) oxygen in minerals, (3) water oxygen, and (4) organic oxygen.

(1) *Atmospheric oxygen.*—In the air oxygen is found free or uncombined, being simply mixed with the other constituents. Oxygen constitutes about one-fifth of our entire atmosphere, which means that in the air resting upon one acre of the earth's surface there are over 10,000 tons of oxygen.

(2) *Oxygen in minerals.*—Nearly one-half of the crust of the earth consists of oxygen, which is in various forms of combination with many other elements.

(3) *Water oxygen.*—Eight-ninths of water by weight consists of oxygen.

(4) *Organic oxygen.*—Over one-third of all animal and vegetable substances consists of oxygen.

HYDROGEN

Hydrogen is present in plants in very much smaller amounts than is carbon or oxygen, constituting only 6 or 7 per cent. of the dry matter of plants.

Source.—Hydrogen is rarely found in nature in other than combined form. We can conveniently classify its compounds as (1) water hydrogen, (2) mineral hydrogen, (3) organic hydrogen, (4) acid hydrogen.

(1) *Water.*—This is the most abundant hydrogen compound and contains one-ninth of its weight as hydrogen. This is the source of hydrogen in plants.

(2) *Mineral sources.*—Many compounds in the crust of the earth contain hydrogen. Minerals containing water in some form of combination are called *hydrated.*

(3) *Organic hydrogen.*—All plant and animal tissues contain hydrogen in many different organic compounds.

(4) *Acid hydrogen.*—Hydrogen is a characteristic constituent of all acids (p. 30).

CHAPTER V

ACTION AND DISTRIBUTION IN PLANTS OF PLANT-FOOD ELEMENTS

It is a matter of practical interest and importance to know in what way different plant-food elements are of value in the growth of plants. We know that in the animal body certain food constituents perform definite duties peculiar to each and that one cannot take the place of another in the processes of nutrition. In a similar way, each constituent of plant-food, as we shall see, performs some function or displays some activity peculiar to itself. We may, for the sake of a general illustration, regard the plant as a factory in which the labor is carefully and systematically distributed; each plant-food element may be regarded as a specialist and as having a kind of monopoly in the field of its specialty. These specialists are mutually interdependent and must all work together in order to produce best results. If one element overdoes its part or shirks its duty, the harmony of action is disturbed and the output is liable to be abnormal in amount or quality.

We shall find it interesting also to notice how the elements are distributed in plants in a way to indicate the location and, to some extent, the character of their activities.

While the organic or air-derived elements (carbon, hydrogen, nitrogen, oxygen) contribute most of the material of which plants are made, we shall be able to see that the mineral elements have functions in plant nutrition that are so important as to make their presence absolutely essential and that no one element can take the place of any other to any marked extent, if at all.

NITROGEN

In the study of plant nutrition, especially in reference to its practical applications to crop growing, no element has probably received so much attention as nitrogen. This element is present in the dry matter of plants to the average extent of only 1.5 per cent., and yet its compounds are of the highest value in agriculture as well as in commercial industries. The agricultural importance of nitrogen is indicated by the following facts: (1) This element is an essential constituent of plant-foods; (2) the amounts of nitrogen ordinarily available in nature for immediate use are very small: (3) nitrogen is one of the elements of the soil that is most heavily used by crops; (4) of all forms of plant-foods in commerce nitrogen is and always has been the most expensive; (5) nitrogen is the most elusive of plant-food constituents, since it changes sooner or later into some form that is easily lost to soil and plant (p. 179).

Action of nitrogen in plants.—The nitrogen-containing compounds in plants are of peculiar importance in relation to the life and growth of plants, since they form an essential part of an important substance known as *protoplasm* (p. 162), which is the living part of plant-cells. On account of this relation no other substance can so quickly show its beneficial effect upon plant growth as nitrogen, when properly applied.

The influence of nitrogen upon plant growth is shown by several striking effects, which are more or less closely associated together, but which for convenience we will consider under separate heads, as follows: (1) Growth of foliage, (2) flowering process, (3) maturing of plants, (4) color of plants, (5) regulation of plant growth, (6) quality of crops, (7) health of plants, and (8) composition of plant.

(1) *Effect of nitrogen on growth of foliage.*—Nitrogen

is intimately associated with the formation of leaves and stems in plants; an abundance of nitrate promotes their growth, and the presence of a copious supply of this plant-food is shown in no way more quickly than by the extreme luxuriance of stem and leaf growth. This effect is of the highest importance, because we must have, as a necessary preliminary for complete development of plants, a good growth of leaf and stem, since the leaves especially constitute the working laboratory of the plant, and in the case of many crops the foliage itself is the product for which the crop is grown, as, for example, celery, lettuce, cabbage, cauliflower, grasses, etc. Lack of nitrogen results in a general decreased or stunted growth of a plant. In the case of a grain crop, like wheat or barley, for example, the stems will be short and the leaves small; the weight of straw in comparison with the weight of grain will be less than in case of a crop grown under normal conditions of nitrogen supply.

(2) *Effect of nitrogen upon the flowering process.*—The growth of flowers is retarded by an abundance of nitrogenous plant-food. Ordinarily, most plants at a certain stage of growth cease to produce new branches and leaves and no longer increase those already formed, but commence to produce flowers and fruits for the development of seed with which to perpetuate the species. If a plant is provided with all the nitrate nitrogen it can use just at the time its flower-buds begin to develop, other conditions being kept normal, the process of flower formation may be checked, while the activity of growth is transferred back to, and renewed in, stems and leaves, which take on a new vigor, multiply and show remarkable luxuriance. Should flowers be developed under such conditions, they are apt to be sterile, producing either no seed or only unproductive ones.

(3) *Effect of nitrogen upon the maturing of plants.*—From what has preceded, it can be readily inferred that

the effect of furnishing crops large amounts of available nitrogen is to retard the maturing process, since the vegetative activity is then carried on in the leaves and stems of plants at the expense of flower and fruit. A crop grown on a soil excessively rich in nitrogen always shows a tendency to ripen slowly; it is late and shows overgrowth of leaves and stems, which, in the case of a grain crop, often results in a tendency to lodge badly before maturity, due to the formation of long-jointed, soft, weak stems.

(4) *Effect of nitrogen upon color of plants.*—The presence of an abundant supply of nitrogen in plants is usually accompanied by a deep green color of foliage, which is regarded as a sign of vegetative activity and health. The substance that imparts green color to plants is called *chlorophyl* (p. 163), which is present in the living, active cells of plants, forming only a small part of the cell contents. It is a somewhat complex substance, containing several different compounds. Nitrogen in combination with other elements is a prominent constituent of chlorophyl. Protoplasm and chlorophyl are intimately associated and their united action is responsible for combining plant-food elements into the compounds manufactured in the plant. Therefore, it can be readily seen why nitrogen is closely connected with the production of green color in plants and why this is a sign of vegetative vigor and activity.

An important application of this effect of nitrogen is seen in the growing of fruits like apples. In the case of apples grown with larger amounts of nitrogen, the color of the fruit is greener; this is noticeable in the case of red apples grown on tilled soils as compared with sod. (p. 679).

(5) *Effect of nitrogen in the regulation of general plant-growth.*—As a result of the effect of nitrogen in influencing the growth of plant foliage, we may say that the amount of

nitrogen regulates the general growth of the whole plant and, therefore, ***the amount of plant-food constituents that a plant can use.*** For example, it does not matter how large amounts of available phosphorus and potassium com-

EFFECTS OF SODIUM NITRATE ON GROWTH OF STEMS AND LEAVES

Corn was grown on an artificial soil containing only small amounts of nitrogen. Nitrate was added to 2 but not to 1. CONNECTICUT (NEW HAVEN) STATION.

pounds there may be in a soil; the amount of these constituents used by a crop is more or less regulated by the amount of nitrogen at hand, within reach of the crop. This is one of the reasons why nitrogen is so highly important in the feeding of plants.

(6) *Effect of nitrogen on quality of crops.*—The quality of crops is affected by the amount of nitrogen used by a crop. Large applications cause softness of tissues, which may be desirable or undesirable, according to the kind of crop. In the case of crops in which decided succulence, tenderness and crispness are desired, such as lettuce, celery, asparagus, etc., relatively large amounts of nitrogen are needed. In the case of cabbages and similar vegetables, large amounts of nitrate produce rapid growth and delicious, tender crispness, but their keeping quality is impaired. For immediate consumption one can, therefore, use larger amounts of nitrogen than when the crop is to be stored for a considerable length of time. The quality of grain is seriously affected by too much nitrogen. Wheat, for example, is lighter, weighs less per bushel, while in the case of barley the berry is light in weight, thick-skinned in appearance and unsatisfactory for malting purposes.

(7) *Effect of nitrogen upon the resisting power of plants.*—Excessive use of nitrogen in growing crops is liable to make them less resistant to the attack of fungous diseases. This is a matter of common experience. Nursery stock grown on land that has been fertilized exclusively for years with large amounts of farm manure is known to be susceptible to plant-diseases and, in some cases, also to attack of some insects. Rust is more abundant on wheat crops which have been too heavily fed with nitrogen. Greenhouse crops are grown on soils very rich in nitrogen and much trouble is experienced with plant-diseases. Shrubbery and young trees which have been pushed too rapidly in the growth of new wood by excessive feeding with nitrogen, are less resistant to the effects of severely cold weather.

(8) *Effect of nitrogen upon the composition of plants.*—While the changes in composition of plants due to use of increasing amounts of nitrogen are not large, the fact

of such a tendency is well established, showing that both the straw and grain of plants grown with large amounts of nitrogen contain somewhat more of this element.

Distribution of nitrogen in plants.—In the growing plant, the nitrogen is present in larger proportions, first in the leaves and finally in the seeds; it is found as a living constituent of the protoplasm (p. 162) and as a reserve food in the cells. Nitrogen is prominent in the *living* parts of plants; in the inactive or formerly living portions, it appears as a remnant. These statements are illustrated by the following figures:

TABLE 7—POUNDS OF NITROGEN IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Lbs. of nitrogen	Variety and part of plant	Lbs. of nitrogen
BALDWIN APPLES		GARDEN PEAS	
Fruit	2.8	Seeds	44.5
Leaves	18.4	Pods	18.7
New wood	9.2	Leaves	38.5
GOLDEN SWEET		Vines	12.2
Flesh of apple	3.8	BEETS	
Skin	4.7	Roots	31.0
Core	10.4	Tops	30.1
Leaves (old)	8.1	Young tops and roots	41.3
New wood	9.7	WHEAT	
GRAPES		Grain	23.0
Berries	8.2	Straw	6.0
Leaves	16.9	OATS	
New wood	5.4	Grain	18.8
RASPBERRIES		Straw	5.3
Berries	12.1	CORN	
Leaves	23.3	Kernels	18.8
New wood	7.6	Leaves and stalks	11.5
Old wood	4.3	PEAS	
ASPARAGUS TOPS		Seeds	41.8
May 5	23.1	Straw	16.6
Aug. 18	13.2		
Berries	24.5		

PHOSPHORUS

Phosphorus compounds are found everywhere in soils and are of great value in their relation to plants. The phosphorus present in bones in the form of calcium phosphate is taken into the animal body in the foods. All plants used as food contain small amounts of phosphorus compounds, which they obtain from the soil.

The phosphorus compounds in the foods consumed by animals are largely passed into the excrements. Soils often become deficient in available phosphorus compounds, especially in regions where grain crops are grown continuously for long periods. Phosphorus compounds are found present in seeds in larger amounts than in any other portion of plants.

Action of phosphorus in plants.—In connection with the growth of crops, phosphorus compounds produce several important effects of practical interest, which can be conveniently discussed under the five points following: (1) Effect on germination of seed, (2) effect on early ripening, (3) effect on relation of grain and straw, (4) effect on nitrogen in grain, and (5) relation to protoplasm.

(1) *Effect of phosphorus upon germination of seed.*—Available phosphorus compounds favor rapid development of the young seedling by stimulating the growth of roots and thus giving the young plant a good start. It has been a familiar practice with progressive farmers to give a crop, corn for example, a generous application of soluble phosphate at the time of planting in order to insure prompt growth of seed and to establish the plant in the soil under conditions favorable to its continued development.

(2) *Effect of phosphorus on early ripening of crops.*—Phosphates tend to favor the early maturing of crops. The formation of grain begins sooner when soluble phosphate is freely used. It has been shown that there may be fully a week's difference in the ripening of field crops due to the generous application of soluble calcium phosphate, other conditions being uniform. This maturing effect of phosphorus is due to the close relation it has to seed production. Plants do not come to maturity and do not produce seeds, unless supplied with available phosphorus compounds. It is not surprising, therefore,

that phosphorus compounds are always found in larger amounts in seeds than in any other part of plants. The ripening effect of phosphorus is just the reverse of that of available nitrogen, which, as we have seen, tends to prolong the season of growth and delay the maturing process, when applied abundantly.

(3) *Effect of phosphorus on relative production of grain and straw.*—Available phosphates, generously used, increase the proportion of grain to straw, which again is the reverse of the action of nitrogen.

(4) *Effect of phosphorus on nitrogen content of grain.*—When available phosphorus compounds are liberally supplied to grain crops, the grain produced contains a smaller percentage of nitrogen than under ordinary conditions; this again is directly opposite to the effect of nitrogen.

(5) *Relation to protoplasm.*—Without phosphorus protoplasm could not exist, and there can be no plant-growth without protoplasm.

Distribution of phosphorus in plants.—The discussion of the action of phosphorus in plant nutrition emphasizes the fact that phosphorus is largely and intimately associated with seed production, as suggested by a recapitulation of the statements already made: (1) Stimulation of seed germination and more rapid development of young seedlings; (2) tendency of generous application of soluble phosphates to favor early maturing of crops; (3) the necessity of abundance of soluble phosphorus compounds for the production of good yields of grain, promoting increase of production of grain in relation to straw; (4) the effect of soluble phosphates upon the composition of the grain, reducing the percentage of nitrogen. These facts are still further emphasized when we examine the different parts of plants with reference to their phosphorus content, as indicated on the next page.

Table 8—Pounds of Phosphorus in 1,000 Pounds of Dry Matter

Variety and part of plant	Phosphoric acid (P_2O_5)	Equal to phosphorus (P)	Variety and part of plant	Phosphoric acid (P_2O_5)	Equal to phosphorus (P)
Baldwin Apple			Garden Peas		
Fruit	1.3	0.6	Seeds	11.2	4.8
Leaves	2.8	1.2	Pods	3.5	1.5
New wood	3.5	1.5	Leaves	5.0	2.2
Golden Sweet			Vines	2.5	1.1
Flesh of apple	1.3	0.6	Beets		
Skin	1.5	0.7	Roots	6.2	2.7
Core	3.1	1.3	Tops	7.5	3.2
Leaves (old)	1.2	0.5	Young roots and tops	10.1	4.4
New wood	3.0	1.3	Wheat		
Grapes			Grain	9.5	4.1
Berries	3.6	1.6	Straw	2.7	1.2
Leaves	3.2	1.4	Oats		
New wood	1.6	0.7	Grain	6.4	2.8
Raspberries			Straw	2.1	0.9
Berries	5.6	2.5	Corn		
Leaves	4.5	2.0	Kernels	6.4	2.8
New wood	2.3	1.0	Leaves and stalks	4.4	1.9
Old wood	0.9	0.4	Peas		
Asparagus Tops			Seeds	10.2	4.4
May 5	7.4	3.2	Straw	4.4	1.9
Aug. 18	3.3	1.4			
Berries	7.6	3.3			

POTASSIUM

Action of potassium in plants.—Potassium compounds are essential to several of the important forms of activity in plant life. Generally speaking, they are most abundant in young and growing parts where vegetative activity is greatest and least abundant in the older parts that have ceased to grow. The effect of potassium upon plant growth and products is shown in many different ways, which will be noticed under the following headings: (1) Effect upon formation of carbohydrates, (2) effect on formation and transference of starch, (3) effect on growth of stems and leaves, (4) effect on fleshy fruits, (5) effect on plant-cells, (6) relation to protoplasm, (7) relation to plant acids, (8) effect in prolonging growing period, (9) effect on plant resistance, and (10) effect on leguminous crops.

(1) *Influence of potassium upon formation of carbohydrates.*—In order that a plant may produce starch, sugar, cellulose and other carbohydrates, potassium compounds are absolutely necessary. In some way, not yet clearly understood, the presence of potassium is necessary to enable the plant to combine the carbon, hydrogen and oxygen furnished by carbon dioxide and water, and thus it influences and makes possible the process of assimilation by which these elementary constituents are built into carbohydrate products.

(2) *Effect of potassium upon formation and transference of starch.*—It is believed that potassium aids in doing important work, not only in the formation of carbohydrates, but also in the transference of starch from one part of a plant to another. One of the chief forms of vegetative activity in leaves is the formation of starch; as first produced in the leaf the starch is insoluble, but in some way it is changed into soluble compounds within the plant-cells and is then able to pass through the cell-walls gradually and later to be carried into the fruit or seed where it accumulates and changes back to its usual insoluble condition. Potassium, as well as calcium (p. 77), appears to be essential in rendering assistance in some way in the performance of these important duties in association with other elements.

(3) *Effect of potassium upon growth of stems and leaves.*—Potassium compounds are important in plant nutrition because they have a marked influence upon the development of leaves and of woody parts of stems. When potassium is deficient in a plant the stems are apt to be weak and brittle. The close relation of this plant-food constituent to the development of leaves and stems is suggested by the fact that larger amounts of potassium compounds are found in these portions of plants than in any other part. This fact is consistent also with the

function potassium compounds perform in the manufacture of carbohydrates, as already pointed out.

(4) *Effect of potassium upon fleshy fruits.*—It is commonly believed that potassium compounds are requisite to a normal development of the fleshy portions of fruits. This is supported by the following results of analysis of several varieties of grapes:

TABLE 9—POUNDS OF POTASSIUM IN 1,000 POUNDS OF DRY MATTER

Variety	Berries		Leaves		New wood	
	Potash (K_2O)	Equal to potassium (K)	Potash (K_2O)	Equal to potassium (K)	Potash (K_2O)	Equal to potassium (K)
Delaware	21.0	17.4	10.0	8.3	6.4	5.3
Concord	16.8	14.0	16.2	13.5	6.6	5.5
Catawba	16.4	13.5	11.0	9.1	6.0	5.0
Diamond	13.6	11.2	10.7	8.9	8.7	7.2

(5) *Effect of potassium on plant-cells.*—In order that plant-cells may satisfactorily do their work of manufacturing plant compounds from its food constituents, it is necessary that the cells be somewhat swollen and turgid (p. 146). Potassium compounds are believed to be the mineral compounds mainly associated with this important action.

(6) *Relation of potassium to protoplasm.*—Although potassium is not a constituent of protoplasmic substances, it appears to be intimately associated with the formation and activity of protoplasm, since it is present in largest amounts in the growing portions where vegetative activity is most intense.

(7) *Relation of potassium to plant acids.*—Potassium compounds are present in those plant juices which are rather sour. In these cases, potassium is combined as an acid salt (p. 19) with such organic acids as tartaric, oxalic, citric, etc. For example, the acidity of grapes is due to the acid salt, potassium acid tartrate

($KH.C_4H_4O_6$); the sourness of sorrel comes from acid potassium oxalate ($KH.C_2O_4$).

(8) *Effect of potassium in prolonging period of growth.*—A relative excess of potassium compounds supplied to a crop tends to prolong the period of growth in stems and leaves and thus delays the maturing of the crop. In this respect it resembles the effect of nitrogen.

(9) *Effect of potassium upon resistance to disease.*—Potassium compounds appear to enable plants to withstand more effectively attacks of fungous diseases. For example, in the absence of sufficient potassium, wheat is liable to rust. Grasses on soils poor in potassium compounds are liable to various fungous diseases. In general, crops which do not receive their full supply of potassium are more liable to disease, and in this condition the resisting power is weakened still more if the plant receives large amounts of available nitrogen.

(10) *Effect of potassium on leguminous crops.*—Potassium compounds produce a pronounced, favorable effect upon the growth of the leguminous crops, clovers, alfalfa, beans, peas, etc. When potassium compounds are applied to soils deficient in this plant-food element, as sandy and gravelly lands, the effects upon the growth of leguminous crops are usually very marked. In what way potassium does this work is not definitely known, but it has been suggested that it promotes the growth of the bacteria associated with the formation of the root-nodules by furnishing them abundant supplies of carbohydrates (p. 218).

Distribution of potassium in plants.—The data in the following table illustrate the relations of potassium to the different parts of plants.

TABLE 10—POUNDS OF POTASSIUM IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Potash (K_2O)	Equal to potassium (K)	Variety and part of plant	Potash (K_2O)	Equal to potassium (K)
BALDWIN APPLE			GARDEN PEAS		
Fruit	6.9	5.7	Seeds	17.2	14.3
Leaves	4.3	3.5	Pods	17.0	14.1
New wood	4.6	3.8	Leaves	34.3	28.4
GOLDEN SWEET			Vines	36.0	30.0
Flesh of apple	7.5	6.2	BEETS		
Skin	10.3	8.5	Roots	62.6	52.0
Core	12.0	10.0	Tops	49.5	41.2
Leaves (old)	4.3	3.5	Young tops and roots	72.1	60.0
New wood	5.4	4.5	WHEAT		
GRAPES			Grain	6.4	5.4
Berries	15.9	13.0	Straw	5.8	4.8
Leaves	12.1	10.0	OATS		
New wood	5.4	4.5	Grain	4.9	4.0
RASPBERRIES			Straw	11.3	9.3
Fruit	15.6	13.0	CORN		
Leaves	10.6	9.0	Kernels	3.8	3.2
New wood	5.0	4.1	Leaves and stalks	19.1	16.0
Old wood	3.5	3.0	PEAS		
ASPARAGUS TOPS			Seeds	11.4	9.5
May 5	16 6	14.0	Straw	12.4	10.3
Aug. 18	25.6	21.0			
Berries	18.0	15.0			

CALCIUM

Some of the practical relations of calcium compounds in the growing of crops have been long appreciated in practice, though the exact reasons for the results obtained were not understood, and especially so far as the plant itself was concerned. We are here interested, not in the action of calcium compounds on the soil, which will be taken up later (p. 373), but in their action in the plant as a source of plant nutrition.

Action of calcium on plants.—Some of the functions of calcium in plant nutrition are fairly well known, at least by inference, though the evidence may be, perhaps, not yet regarded as actually established beyond doubt. We can consider the effects and relations of calcium in plants under four heads, as follows: (1) Effect on cell-walls, (2) effect on transportation of starch, (3) effect on root-hairs, and (4) relation to acids.

(1) *Effect of calcium on cell-walls.*—One of the probable, important functions of calcium compounds is to aid in the growth and solidification or strengthening of cell-walls.

(2) *Effect of calcium on transportation of starch.*—Calcium, as well as potassium (p. 73), appears to be associated with the transference of starch in plants. Starch in the form of insoluble granules is known to be formed in the leaves of plants; sooner or later it is in some way changed into a soluble form within the plant-cells and is then able to pass through cell-walls gradually and later be carried into the fruit or seed, where it accumulates and may change back to its insoluble, granular condition. This function was formerly thought to depend chiefly upon the presence of potassium compounds, but the exact relations of different elements to the changes cannot be regarded as known with a satisfactory degree of fullness or certainty.

(3) *Effect of calcium upon the development of root-hairs.* It has been noticed that in the absence of calcium compounds root-hairs (p. 164) do not develop as profusely as they do when such compounds are abundant.

(4) *Relation of calcium compounds to acids.*—Calcium is found in plants in combination with different acids, especially oxalic, forming calcium oxalate, which can often be seen in the form of small crystals. It is inferred that in uniting with oxalic acid and forming calcium oxalate, which is not soluble in water, the calcium is utilized to remove the oxalic acid in this way and thus neutralize its injurious effects when present as an uncombined acid. Calcium is also found in plants as carbonate and phosphate and sometimes as sulphate.

Distribution of calcium in plants.—In a study made by the author of the composition of the fruit, leaves and new wood in several varieties of fruit trees and bushes, it was shown that the new wood uses more than three times the

amount of calcium used by the fruit, while the leaves use over fifteen times as much as the fruit. Calcium is thus seen to be present in largest amounts where there is the greatest vegetative activity. Calcium is found most abundantly in those tissues that have attained their growth, and in which there is going on the work of food-making in the chlorophyl-containing cells of leaves, etc. Calcium is less abundant in those organs of the plant in which the manufactured foods are stored, and in dead parts such as old wood. These statements are illustrated in the following figures:

TABLE 11—POUNDS OF CALCIUM IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Pounds of calcium (Ca)	Variety and part of plant	Pounds of calcium (Ca)
BALDWIN APPLE		BEETS	
Fruit	0.3	Roots	1.6
Leaves	22.0	Leaves	21.4
New wood	1.8	TURNIPS	
PEACHES		Roots	6.1
Fruit pulp	0.6	Leaves	27.3
Stones	0.4	WHEAT	
Leaves	34.8	Grain	0.5
New wood	1.9	Straw	2.1
PEARS		OATS	
Fruit	0.6	Grain	0.1
Leaves	20.3	Straw	3.0
New wood	11.4	CORN	
PLUMS		Kernels	0.3
Fruit pulp	0.7	Leaves and stems	4.3
Stones	1.0	PEAS	
Stems	18.1	Seeds	1.0
Leaves	30.3	Straw	15.4
New wood	17.6		

MAGNESIUM

Magnesium was formerly regarded as of secondary importance in relation to plant nutrition, but an increased knowledge of what it does in plants has shown it to be of much importance. It is absolutely indispensable to all plants. While magnesium and calcium have points of

close chemical resemblance, neither one can take the place of the other in their relations to plant life.

Action of magnesium in plants.—The work of magnesium in plants is less understood even than that of calcium. We will consider four points in this connection, as follows: (1) Relation to seeds, fruit, etc., (2) relation to proteins, (3) relation to chlorophyl, (4) effect as poison.

(1) *Relation of magnesium to seeds and other parts of plants.*—Magnesium compounds accumulate in seeds, fruits, flowers, roots and tubers to a larger extent than does calcium, but less in stems, leaves and wood, while the reverse is true of calcium. Hence, magnesium compounds appear especially important in the formation of seeds.

(2) *Relation of magnesium to proteins.*—Magnesium, though not a constituent element of protoplasm (p. 162), appears to be associated with nitrogen compounds in the protoplasm in the formation of proteins. Its special value is thought to consist in aiding in the assimilation of phosphates.

(3) *Relation of magnesium to chlorophyl.*—Magnesium is believed to be an essential constituent of chlorophyl (p. 163) and, therefore, of use in the formation of starch.

(4) *Effect of magnesium compounds as poisons.*—Magnesium compounds, especially the chloride, may act as a poison and injure plants in the absence of calcium compounds. Solutions, even of great dilution, injure plant roots under such conditions. It is held by some that magnesium compounds are injurious to plants when the ratio of magnesium to calcium goes beyond a certain limit, but the exact ratio is a matter of dispute and appears to vary according to many different conditions.

Distribution of magnesium in plants.—The distribution of magnesium compounds, as already stated, appears to be marked in amount in seeds, fruits, flowers, roots and

tubers, in comparison with calcium, but the reverse in leaves, stems, straw and new wood, as illustrated by the following figures, which should be compared with those in Table 11:

TABLE 12—POUNDS OF MAGNESIUM IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Pounds of magnesium (Mg)	Variety and part of plant	Pounds of magnesium (Mg)
BALDWIN APPLE		**BEETS**	
Fruit	0.6	Roots	1.8
Leaves	6.3	Leaves	10.2
New wood	0.3	**TURNIPS**	
PEACHES		Roots	1.8
Fruit pulp	1.0	Leaves	2.8
Stones	0.1	**WHEAT**	
Leaves	8.8	Grain	1.6
New wood	0.3	Straw	0.8
PEARS		**OATS**	
Fruit	0.6	Grain	1.6
Leaves	4.2	Straw	1.3
New wood	1.8	**CORN**	
PLUMS		Kernels	1.3
Fruit pulp	0.9	Leaves and stems	1.8
Stones	0.9	**PEAS**	
Stems	4.3	Seeds	1.3
Leaves	8.0	Straw	2.6
New wood	3.2		

SULPHUR

It is well established that in the entire absence of sulphur compounds (sulphates) plants do not grow, although the amount required is small.

Action of sulphur in plants.—While much remains to be learned about the relations of sulphur to plant nutrition, a few facts are available that bear on the subject. Two points will be mentioned in this connection: (1) Relation to proteins and (2) relation to certain oils.

(1) *Relation of sulphur to proteins.*—Sulphur is always a constituent of protoplasm and also of plant proteins. Therefore, whatever specific work it may do in plant nutrition, its action is important.

(2) *Relation of sulphur to odorous oils.*—Sulphur is a constituent of mustard oil, which imparts characteristic flavors to cruciferous plants, such as mustard, horse-radish, turnip, cabbage, etc. Sulphur is also contained in garlic oil, the highly odoriferous compound that is characteristic of onions, garlic, leeks, etc.

Distribution of sulphur in plants.—Sulphur compounds occur much more largely in leaves and stems than in other parts of plants, as shown below:

TABLE 13—POUNDS OF SULPHUR IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Pounds of sulphur (S)	Variety and part of plant	Pounds of sulphur (S)
WHEAT		Straw	1.3
Grain	0.04	CABBAGE LEAVES	1.0
Straw	0.5	HORSE RADISH	2.0
OATS		BEETS	
Grain	0.2	Roots	0.1
Straw	0.9	Leaves	3.4
CORN		TURNIPS	
Kernels	0.04	Roots	0.3
Leaves and stalks	1.1	Leaves	4.4
PEAS			
Seeds	0.4		

IRON

Action of iron in plants.—We have some interesting facts about the action of iron compounds in plants, which enable us to state more clearly than in the case of some other elements what its function is. In the absence of iron compounds plants develop no green color, whether with or without sunshine. Unless green plants receive enough iron compounds, no chlorophyl (p. 163) can be formed and therefore no green color, and, further, no normal growth. Although no iron compound appears to be a constituent of protoplasm or of any coloring matter in chlorophyl, yet in some way the presence of an iron compound is absolutely necessary for the production of green

color in leaves, stems, etc. Under some conditions plants fail to assimilate iron and remain white or nearly so, when they are said to be suffering from *chlorosis*, which is regarded as the result of a diseased condition. Sometimes a shoot develops so rapidly that iron compounds do not reach the growing parts quickly enough, and then the newly formed leaves are white instead of green.

Owing to the fact that iron salts are essential to the formation of green color in plants, the opinion has become widely prevalent among farmers, especially fruit growers, that iron compounds are the direct cause of high color in fruit and flowers. This has led to driving nails into fruit trees, or burying iron scraps about the roots, and similar practices. So far as we have any reliable facts bearing on the matter, they are insufficient to justify the theory. No direct evidence has yet been furnished to show that the application of iron compounds has any beneficial effect on either color or yield of fruit.

Distribution of iron in plants.—From the data given below, it is seen that iron is present generally in leaves in larger amounts than elsewhere in plants:

TABLE 14—POUNDS OF IRON IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Pounds iron (Fe)	Variety and part of plant	Pounds iron (Fe)
WHEAT		PEAS	
Grain	0.2	Seeds	0.14
Straw	0.2	Straw	0.6
OATS		BEETS	
Grain	0.3	Roots	0.4
Straw	0.6	Tops	1.5
CORN		TURNIPS	
Kernels	0.1	Roots	0.4
Leaves and stalks	0.8	Tops	1.3

CHLORINE

All plants contain some chlorine, generally as sodium chloride. The necessity of chlorine in plant nutrition

may be regarded as still an unsettled question, although the weight of evidence, on the whole, appears to be against the need of this element in normal plant growth.

Action of chlorine in plants.—Chlorine compounds or chlorides, to be more specific, are needed, if at all, only in the smallest possible proportions. Salt beyond a certain amount acts as a poison to plants, the chlorine and the sodium both acting injuriously. The ability of plants to withstand injurious action of salt is shown by strand and marine plants, which contain much more salt than inland plants and, indeed, an amount that would kill inland plants. For example, some strand plants are not injured by solutions containing 3.5 per cent. of salt, while inland plants are poisoned by solutions containing much less. The large amount of salt in strand plants is due not to the need of the plant but to the presence of so much salt where they grow. Most farm crops can grow in soil that contains 0.25 per cent. of salt.

Distribution of chlorine in plants.—Chlorides accumulate chiefly in the lower portions of plants, apparently as accidental constituents. The following figures illustrate the general location of chlorine in plants:

TABLE 15—POUNDS OF CHLORINE IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Pounds of chlorine(Cl)	Variety and part of plant	Pounds of chlorine(Cl)
OATS		Straw	2.9
Grain	0.3	BEETS	
Straw	3.1	Roots	7.5
CORN		Leaves	25.0
Kernels	0.1	TURNIPS	
Leaves and stalks	0.7	Roots	4.0
PEAS		Leaves	11.8
Seeds	0.4		

SODIUM

Sodium appears as a regular, though small, constituent of plants.

Action of sodium in plants.—It is a disputed question whether sodium performs any necessary function in plants as a food, but the weight of evidence appears to show that it does not. The functions of potassium in plant nutrition cannot be performed by sodium, although it has been shown that, in the presence of an abundance of sodium salts, some plants use less potassium than otherwise, especially when potassium salts are not abundant.

Distribution of sodium in plants.—Sodium is found mostly in the lower parts of plants, very little being present in seeds, as illustrated by the following figures:

TABLE 16—POUNDS OF SODIUM IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Pounds of sodium (Na)	Variety and part of plant	Pounds of sodium (Na)
WHEAT		PEAS	
Grain	0.3	Seeds	0.2
Straw	0.5	Straw	1.6
OATS		BEETS	
Grain	0.4	Roots	9.2
Straw	1.8	Leaves	22.4
CORN		TURNIPS	
Kernels	0.2	Roots	6.0
Stems and leaves	0.5	Leaves	8.3

SILICON

Action in plants.—It appears to be the general belief at the present time that silicon performs no essential function in plant life, its constant presence being due simply to the fact that silicon compounds are in the soil solution and are not taken into the plant because the plant needs or uses it. Silicon compounds are present in such relatively large amounts, especially in the straw of cereals, that it was taken for granted that it must perform some essential function; and the function assigned to it was that of contributing to the stiffness of straw, but it has

been shown that this quality is dependent upon other factors quite independent of the presence or amount of silica. It has been suggested that in some way soluble silicates may enable plants to make better use of insoluble phosphate in soils. While not essential to stiffness, growth or maturing, silicon compounds may be useful in hardening the outer surface and in making projecting parts and the edges of leaves harsh and cutting, as in the case of leaves of corn plant, rushes, etc.

Distribution of silicon in plants.—Silicon is found in largest amounts in the older portions of plants, the leaves, stalks, straw, chaff, etc., especially when vegetative activity has diminished in those parts, as illustrated by the following figures:

TABLE 17—POUNDS OF SILICON IN 1,000 POUNDS OF DRY MATTER

Variety and part of plant	Pounds of silicon (Si)	Variety and part of plant	Pounds of silicon (Si)
WHEAT		PEAS	
Grain	0.2	Seeds	0.1
Straw	14.5	Straw	1.4
OATS		BEETS	
Grain	4.9	Roots	0.6
Straw	13.4	Leaves	2.3
CORN		TURNIPS	
Kernels	0.1	Roots	0.6
Leaves and stalks	6.1	Leaves	1.8

CARBON

The element carbon may be well called the central element of all animal and vegetable substances, for there is not a living thing, from the smallest microscopic cell to the largest known growth, which does not contain carbon as a necessary constituent. Moreover, no other element is contained in the dry matter of plants to so large an extent as carbon, since it constitutes about 45 per cent. of the solid or water-free portion of the whole

vegetable kingdom. That any vegetable or animal substance contains carbon can be easily shown by heating it sufficiently to make it blacken or char. When wood, for example, is thus heated, the different elements of which it is composed are driven off, mainly in the form of invisible gases, but the carbon is the last to go and remains behind as a black substance, familiar to us as charcoal, unless heated higher, when it also burns up and disappears. The so-called humus (p. 117) of soils is vegetable or organic matter which has partially decomposed, leaving behind the carbon, which gives humus its characteristic dark color.

Action of carbon in plants.—Carbon is a constituent of practically all plant compounds, except water, among which are starch, cellulose, proteins, sugars, oils, acids, etc. Hence, its chief function is to furnish the large amount of carbon found in plant compounds. Plants obtain their carbon chiefly by taking in carbon dioxide through their leaves directly from the surrounding air. In the cells of the leaves, the carbon dioxide, in the presence of sunshine, is separated into its two elements, its carbon uniting with other elements to form the various compounds mentioned, most of the oxygen being returned to the air uncombined. Recent investigations seem to indicate that some carbon dioxide is probably taken into the plant through the roots, and also that forms of carbon other than carbon dioxide may be found useful to some extent in supplying plants with their carbon food, but this is at present a matter of scientific rather than practical interest.

In an indirect way, carbon dioxide performs an external service for plants, since the carbon dioxide which is usually contained in soil water in considerable amounts has a pronounced dissolving action upon some of the mineral plant-food constituents of the soil, especially potassium and phosphorus compounds.

Distribution of carbon in plants.—Carbon is distributed in the form of its various compounds throughout all parts of plants; unlike the mineral elements, it is not concentrated in any one place. It is true, however, that some of the specific carbon compounds are locally concentrated, as, for example, sugar and starch in grain, fruit, roots, tubers, etc.

OXYGEN

The element oxygen constitutes about 42 per cent. of the dry matter of plants and is, therefore, second only to carbon in respect to its abundance in the vegetable world. If, however, we consider the green plant and take into consideration the oxygen of the water in the plant, then oxygen constitutes a far larger proportion of growing plants than any other single element; indeed, it amounts to more than all the other constituents put together. Oxygen is present as an important constituent of nearly all plant compounds, and of all important ones.

Action of oxygen in plants.—The primary function of oxygen is to supply plants with the oxygen needed to make the various plant compounds. This oxygen comes largely, if not wholly, from water and not from atmospheric oxygen. However, most plants require some free oxygen in some of their processes. Green plants do not thrive in the absence of oxygen. Seeds require free oxygen for germination. In the process of flowering, the absorption and chemical action of oxygen in the blossom are so marked in some cases as to develop a measurable increase of temperature. Oxygen is needed in the soil for the activity of roots and of micro-organisms as well as for effecting important chemical changes in the soil constituents.

Distribution of oxygen in plants.—Oxygen is dis-

tributed all through the plant in the different compounds of which it forms a part.

HYDROGEN

Action of hydrogen in plants.—The chief function of hydrogen in plants is to furnish the supply needed for the various combinations formed in the plant. The source of supply of hydrogen in plant nutrition is water, which, for this purpose, is separated within the plant into its constituent elements, hydrogen and oxygen, and these are then built into the compounds which it is the function of the plant to elaborate.

As a constituent of water, hydrogen along with oxygen performs many important duties in connection with growing plants, and its action will be considered under the subject of water (p. 145).

Distribution of hydrogen.—Like the two other air-derived elements, carbon and oxygen, hydrogen is not concentrated in any particular part, but is distributed through the whole plant.

Up to this point we have learned that there are ten chemical elements essential to plant growth; we have studied in a preliminary way such compounds of these elements as are to have a special interest for us in connection with plant-feeding; we have seen that each plant-food constituent performs a special kind of work and produces specific effects in relation to plant growth; and finally we have observed that all the constituent elements must work together, that while some are used in large, and other in small, amounts relatively, yet all are necessary and no one can take the place of another.

CHAPTER VI

FUNCTIONS AND PHYSICAL PROPERTIES OF SOILS

Having learned something about the elements and compounds that are used by plants as food materials, we will now take up an outline study of the most prominent agricultural source of plant-food, namely, the soil; we shall consider some of its properties that are of special importance in relation to plant growth, showing the interdependent relations existing between the soil, water, plant-food and crop growth.

General relations of soils and plants.—The soil performs two distinct functions in relation to plants: (1) It furnishes for plants a dwelling place or home, in which, under conditions more or less congenial, they begin and continue growth from seed to maturity. (2) The soil is intimately associated with the nutrition of plants, furnishing directly the mineral constituents (p. 16) used by them and serving as a medium for conveying to them a portion of the air-derived constituents (p. 16).

In this chapter we shall consider those conditions which make the soil a genial home for plants and which can be grouped under the general head of physical properties. In the two chapters following we shall study more particularly the chemical composition of soils. We shall see that the physical properties and chemical composition, especially in relation to plant-food supply, are intimately connected.

Soil and subsoil.—When we speak of the soil in connection with agriculture we mean the soft, thin, loose layer or film of earth in which the roots of plants can

grow and from which they obtain their inorganic food supply. It is made up of disintegrated, powdered and partially decomposed rocks, mixed with varying amounts of organic matter formed mostly by decay of vegetable substances.

We distinguish by the name of *subsoil* the layer of earth below the soil proper. While the change from soil to subsoil is gradual, certain properties of the two are quite distinct, among which we notice the following: (1) The soil contains more decaying organic matter (p. 117) than the subsoil, owing to the prevalence of root growth in the upper layer; this tends to make the soil darker in color. (2) Owing to the greater amount of organic matter, micro-organisms are largely confined to the soil, diminishing rapidly in the subsoil and finally disappearing altogether (p. 197). (3) The *texture* (p. 93) of soil and subsoil usually differs, the water carrying the finest particles into the subsoil and leaving the coarser particles in the upper layer. (4) The soil is usually richer than the subsoil in available plant-food, since conditions in the upper layer are more favorable for the conversion of unavailable into available forms.

Formation of soil.—While soil formation is a matter of general interest and often of much importance in connection with the plant-food supply in soils, we do not, for our purpose, need to give more than a few words, in passing, to this subject. The principal part of the soil was once solid rock, and the first step toward the formation of soil was the breaking up and powdering of the rock. The conversion of rocks into soil has been accomplished by means of various agencies, physical and chemical, including biochemical. The chief agents, *acting mechanically*, in rock disintegration are the following: (1) Heat, (2) cold, (3) flowing water, (4) moving ice (glaciers), (5) wave action, (6) winds, (7) vegetable growths, and (8) animals. The more prominent *chemi-*

cal agencies are the following: (1) Oxygen of air, (2) the dissolving effect of water, especially when containing carbon dioxide (p. 60), (3) the action of acid secretions of plant-roots, (4) the decomposition of vegetable and animal matter by micro-organisms (p. 198), and (5) other forms of action by micro-organisms (p. 197). Some of these agencies are more or less intimately associated.

That the soil has come from rocks is conclusively shown by the fact that we are able often to identify minute crystalline fragments of the characteristic minerals originally present in the rock from which the soils have come. The extent to which a soil consists of undecomposed, powdered rock-minerals and of products of rock decomposition depends, among other conditions, upon the kind of rock and the intensity of action of the decomposing agents. In the case of some resistant crystalline rocks, the original rock constituents may not be removed by chemical decomposition more than one-half, while, in extreme cases, 90 per cent. of the rock may be changed. In the case of limestone rocks, the change of original material is always much greater, depending largely upon the purity of the limestone. Not only are the constituents of rocks decomposed, but the compounds into which they are changed by decomposition are frequently soluble and are carried from the surface into the lower portions of the soil.

The value of a soil for agricultural purposes depends upon (1) the original material from which it has been derived, (2) the state of fineness to which it has been reduced, and (3) the extent of loss it has undergone through chemical decomposition and leaching of essential plant-food constituents. In the processes of soil decomposition, there is a larger proportional loss of compounds containing calcium, magnesium and potassium.

PHYSICAL PROPERTIES OF SOILS

Under this head, we study those factors in the soil which contribute to make a comfortable home for plants or, more particularly, for the roots of plants. It is, therefore, pertinent to inquire at this point: (1) What important work do roots perform for plants? (2) What are the soil conditions essential for doing their work?

Function of plant-roots.—The important things that roots do for plants in relation to the soil are the following:

(1) *Mechanical support.*—Roots serve to hold plants firmly in place. They penetrate the soil downwards and sideways, bracing the plant firmly in its upright position.

(2) *Absorbents of food materials.*—From the soil roots absorb water containing dissolved plant-food materials. How this is done we will consider later (p. 166). Roots are the feeding-organs of plants in relation to mineral plant-food.

Soil conditions essential for work of roots.—In order that plant-roots may do to the best advantage the work for which they are designed, the soil must offer favorable physical conditions, among which we will notice the following:

(1) *Firmness and mellowness.*—For the most favorable condition of root growth, a soil should be firm in order to support the plant in its place, and mellow in order to enable the delicate rootlets to penetrate the soil easily in their search for water and the plant-food dissolved in it.

(2) *Moisture.*—Roots are the organs by which the large amounts of water required for plant growth are taken up, and hence the soil must be sufficiently moist to furnish the needed water.

(3) *Warmth.*—Root cells do not perform their work below certain temperatures and therefore require a soil more or less warm.

(4) *Ventilation.*—Roots must breathe; they must therefore be supplied with atmospheric oxygen. This means that the soil must be well ventilated by being kept in a somewhat porous or open condition, as opposed to too great compactness.

From the preceding statements it is obvious that the physical properties which agricultural soils should possess are (1) firmness, (2) mellowness, (3) ability to hold enough moisture and not too much, (4) the power of absorbing and retaining heat, and (5) a porous, open condition that permits sufficient circulation of air, but not too much. These physical properties are dependent upon the mechanical condition of soils, which, in turn, is governed by the fineness and arrangement of the particles of which the soil is made up. This brings us to a study of *soil texture* and *soil structure.*

Soil texture.—The physical properties of soils are, in a large measure, primarily dependent upon the size of the individual particles. In speaking of the size of the individual particles contained in soils, we use the word *texture.* The fineness of division required in the particles of a good agricultural soil is not easily appreciated. According to reliable estimates, a single ounce of good soil contains many *thousand millions* of separate particles. If the surfaces of all the particles in one cubic foot of soil could be spread out in one continuous surface, they would cover an area of one to three acres, varying according to the fineness of the particles; and it is to be kept in mind that this great spread of surface in each cubic foot of such soil can be made accessible to the root systems of plants. It should be mentioned in passing that soil particles vary greatly in shape; some are rounded and smooth; others are irregular, angular, jagged or somewhat rounded or smoothed fragments.

The mineral or inorganic constituents of the soil vary in size all the way from large stones and coarse sand to

finest dust. The number of particles of any one size varies greatly in different soils. The relative amounts of coarse and fine particles can be used as a basis for classifying soil material into textural groups, since the physical properties are largely affected by the proportions of different-sized particles.

Classification of soil materials according to texture.—The inorganic materials which are to be considered in the physical make-up of soils may be divided into the following groups or classes, according to fineness or coarseness of texture: (1) Coarse part, (2) sand, (3) silt and (4) clay. We will now consider briefly the properties of these different textural groups, which are sometimes spoken of also as "soil separates."

(1) *Coarse part.*—This includes all material larger than one twenty-fifth of an inch in diameter and is divided into two parts, (1) *gravel* and *stone*, all material larger than two twenty-fifths of an inch in diameter, and (2) *fine gravel*, all material smaller than two twenty-fifths and larger than one twenty-fifth of an inch in diameter.

(2) *Sand*, as applied to the texture of soils, includes those particles whose size is between one twenty-fifth and one five-hundredth of an inch in diameter. This group is subdivided into four subgroups or grades: (a) coarse, (b) medium, (c) fine and (d) very fine sand, which may be regarded as roughly corresponding in size, respectively, to the grains in coarse, medium and fine granulated sugar and fine table salt.

Sand, in the ordinary chemical sense, consists, when pure, of grains of quartz or silicon dioxide (SiO_2), also called silica (p. 59); the quartz particles come from the original rock material of the earth. They are more or less rounded as the result of constant rubbing and wearing under the action of moving water. As a matter of fact, sand particles are generally made up in large part of quartz or silica because of the hardness of the original

rock from which the particles come; such material resists chemical and physical action; the remnants due to such action are left, in large part, as more or less coarse sand particles. But sand, as applied to soil texture, usually contains also worn fragments of resistant minerals other than silica. Generally speaking, the finer the sand particles, the larger is apt to be the amount of mineral fragments other than silica, and, therefore, of plant-food material. Sands are generally more or less colored by admixture of iron compounds (p. 58). In the case of sands on seashores bordered by coral rock, the grains consist largely of calcium carbonate.

Whatever their origin or the composition of the constituent grains, sands are distinguished by one physical peculiarity, namely, the particles in a mass lack coherence when dry and easily fall apart.

(3) *Silt* includes soil particles varying in size between one five-hundredth and one five-thousandth of an inch in diameter. In its physical properties, it is intermediate between sand and clay. When wet, silt feels fine, smooth and sticky like clay. If a soil containing a large amount of silt and clay is shaken up with water and then allowed to stand, the silt settles slowly, while the clay remains suspended through the water a much longer time. A good illustration of silt is seen in the fine deposit in ditches and drains in which water moves slowly.

(4) *Clay*, as applied to soil texture, refers only to the size of the particles without reference to chemical composition. It includes all particles whose size is less than one five-thousandth of an inch in diameter.

Considered chemically, pure clay is a compound containing aluminum, silicon, hydrogen and oxygen, known as kaolinite or hydrated aluminum silicate ($Al_2Si_2H_4O_9$ or $\underset{\text{Aluminum oxide}}{Al_2O_3}$, $\underset{\text{Silicon dioxide}}{2SiO_2}$, $\underset{\text{Water}}{2H_2O}$), which results largely from the decomposition of feldspar. Particles having the clay texture generally contain silicate or

real clay particles in large proportions, because the original silicate minerals from which the particles come are not sufficiently resistant to withstand the forces that grind them into the fineness of clay texture; but they also contain, in variable though not large proportions, small grains of silica or quartz and fragments of broken-down minerals other than silicates. The reddish color commonly associated with many clays is due to the presence of iron compounds.

Clay particles in mass possess certain characteristic properties, which are in marked contrast to those of the sand texture; the larger the proportion of particles of clay texture in a soil, the stronger will be the manifestation of the characteristics peculiar to clay texture. These peculiarities we will consider briefly under the following terms: Puddling, plasticity, shrinking, suspension and flocculation.

(a) Puddling. When clay in a wet condition is worked or stirred, its constituent particles fall apart and become individually separate. This process is known as *puddling*. In this condition clay is impervious to air or water.

(b) Plasticity. Clay is very plastic in moist condition; it can be molded into any desired shape, which it retains on drying, and does not, like sand, fall apart into separate particles.

(c) Shrinking. When wet clay dries, it shrinks considerably and becomes so hard and tough that the mass can be broken or made fine only with difficulty. Owing to this property, the surface of wet clay soils splits into numerous characteristic cracks on drying.

(d) Suspension in water. When clay is stirred up with water, the finer particles remain in suspension a long time and the water may remain turbid for days or even weeks before all the particles completely settle and leave the water clear. This property is well illustrated by the water of some turbid rivers.

(e) **Flocculation.** This subject is discussed on page 104.

The characteristic properties of clay particles are due not so much, if at all, to chemical composition, as to their fineness of division. A mass consisting of pure clay (kaolinite) shows, on being powdered, the physical prop-

LOSING WATER FROM THE SOIL

The soil is cracked to some depth below. Soil moisture is fast leaving the ground, and the soil is in bad physical condition. New York (Cornell University) Station.

erties of clay only when the size of the particles is reduced beyond a certain degree of fineness; large particles in mass possess no plasticity and on drying fall apart easily into powder, behaving much like quartz particles of the same size. On the other hand, pure quartz when reduced to particles as small as those of clay shows all the characteristics of clay particles of the same size. As

a matter of fact, it is generally true that in the very fine particles of soils kaolinite particles predominate, because the material from which this is formed by chemical decomposition naturally undergoes more extensive powdering by the action of water and weathering. In the case of sand particles, its grains are apt to be made up of quartz, because this material is so hard as to resist the agencies that produce fine particles in the case of less resistant material. Grains of quartz or silica are therefore more abundant in the coarser parts of soils. While we can distinguish chemically between pure sand (quartz) and pure clay (kaolinite), the chemical distinction does not apply sharply to the materials, sand and clay, when considered in their relations to texture, because particles of clay texture generally contain some quartz.

Classification of agricultural soils on the basis of texture.—The physical properties of soils vary according to the varying proportions of the different-sized soil particles they contain. For our purpose, soils can be considered under three general types or classes, (1) sandy, (2) clay and (3) loam, some of the main characteristics of which we will briefly state.

(1) *Sandy soils.*—In soils characterized as sandy, the amount of silt and clay particles is relatively small (usually less than 20 per cent.), the larger portion consisting of sand particles of different grades of fineness. Soils made up wholly of sand have little or no agricultural value. Soils with so high a percentage of sand particles as to be distinctly sandy have the following characteristics: (a) They permit water to pass downward too rapidly; (b) they admit air too freely, causing too rapid destruction of organic matter; (c) they absorb heat too rapidly, which results in excessively rapid evaporation of soil moisture, marked heating of the soil, and, in consequence, a premature ripening and even burning or drying of crops; (d) their absorbent and retaining powers

with reference to soluble compounds are slight, and plant-food leaches rapidly when the rainfall is abundant.

With increase of silt and clay, these properties are favorably modified. The texture of sandy soils can be changed by application of clay soil, but it is rare that this procedure is economically practicable. Little can be done to make a very sandy soil into a good crop-bearing medium.

It is common to speak of sandy soils as light, because the particles move freely; they are loose and easy to work, offering little resistance.

(2) *Clay soils.*—In their physical properties, clay soils containing large proportions (35 per cent. or more) of very fine-textured particles are the reverse of sandy soils, as indicated by the following statements: (a) They hold water very tenaciously and have a tendency to be deficient in ease of drainage; (b) they are much less accessible to air, and on this account organic matter decomposes slowly; (c) they are commonly known as cold soils; (d) clay soils are often called heavy because the particles stick together; they easily become compact, are hard to work and do not allow plant-roots to penetrate easily; (e) after rains, clay soils quickly bake and harden on the surface so that when worked later the soil breaks into hard lumps; (f) when worked in too wet a condition, clay soils become "puddled," that is, the crumb-structure (p. 101) is destroyed and the individual clay particles are brought into the closest possible contact. This has the effect of making the soil practically impervious to water and air, thus interfering seriously with drainage and ventilation.

By mixing sand that is not too coarse with a clay soil, the compactness of the latter is diminished and it is rendered more porous, admitting air and water more easily. The adverse physical properties of clay soils are also favorably modified by increasing the amount of organic matter (p. 135).

(3) *Loams* are soils intermediate in texture between sand and clay; they contain a mixture of the different textural groups in such proportions that the properties of no one group predominate. In loam soils the particles of sand, silt and clay textures are present in such relative amounts that the excessive porosity of the sand texture and the undesirable compactness of clay are favorably modified. Loams usually possess a desirable structure (p. 101), but are more or less sticky when wet. It is obvious that there must be many varieties of loamy soils, their differences being caused by variation in the proportions of the different textural soil particles contained in them. Thus, we have sandy loams, silt loams, clay loams, gravelly loams, stony loams, etc.

(a) Sandy loams consist of somewhat more than one-half sand with less than one-half of silt and clay. They are among the lightest soils adapted to crop growing. They are usually found useful for such crops as corn, cotton, small fruits and vegetables.

(b) Silt loams consist largely of silt with relatively small proportions of clay and sand. They are intermediate in their physical properties between sand and clay, being more permeable to water than clay and less so than sandy soils. The subsoils of many of the western prairies belong to this type. While difficult to till, they are well adapted, when properly drained, for general farm crops.

(c) Clay loams contain larger proportions of clay than silt loams do. As a rule they are somewhat difficult to manage, since they are inclined to be stiff and sticky, but they are usually regarded as being best adapted of all soils for general farming. When properly managed, they retain their crop-producing powers for a long time.

(d) Gravelly loams consist of coarse-grained particles, varying in proportion from one-fourth to two-thirds,

mixed with sandy, silt or clay loam. Fruit and forest trees do well on some kinds of gravelly loam.

(e) Stony loams consist of sandy, silty or clay loam mixed with stones, the latter varying in proportion from one-fourth to three-fourths. The stones interfere with ordinary methods of tillage and such soils are best utilized for some kinds of fruit and forest trees.

Soil structure.—By structure of soils we mean the manner in which the soil particles are arranged with reference to one another. The particles may be separated for the most part, each being free from the surrounding particles; or the particles may adhere together, forming a group in which they remain united together under ordinary conditions. When soil particles thus adhere, in larger or smaller grains, the structure is known as the *granular* structure or the *crumb* structure. Granules are of all sizes; they may become so overgrown as to interfere with favorable conditions for managing the soil in crop growing, when they are called clods. The tendency to form a crumb-like structure is very strong in clay soils and practically absent in sandy soils.

The character of a soil's structure is usually recognized by the farmer in a practical way through the manner in which it behaves under the plow, whether it plows hard or easy. When a spading-fork is pushed into a soil that is just moist enough to work well and a mass of earth is removed, its structure is readily shown by the way in which it behaves. On being turned over by the spading-fork, the granular, crumb-like structure readily reveals itself. A good loam falls apart easily into the characteristic soil crumbs. A clay loam may need some strokes of the spade to make it crumble and the resulting crumbs will be larger than in loam less clayey. Sandy soils and loams fall apart so readily that it may be difficult to lift a forkful without having it fall apart and run between

the tines. A clay soil is lumpy and falls apart only by vigorous strokes and then not into fine crumbs.

Factors influencing soil structure.—It is of practical importance to know what conditions are favorable to the crumb or granular structure and what to the single-grain structure; and it is desirable especially to study those factors which a farmer can make use of in modifying

A CASE OF BAD SOIL STRUCTURE. NEW YORK (CORNELL UNIVERSITY) STATION

and controlling the soil structure. Control of structure is desirable in connection with loams, silts and clays; the structure of the coarser-textured sandy soils is difficult to modify appreciably by practicable means. The following conditions are among those that affect soil structure: (1) Variation of moisture, (2) freezing, (3) cultivation, (4) organic matter, (5) growth of roots, (6) soluble salts, (7) animal life, (8) hard rains. We shall

briefly state the facts regarding these factors without attempting to explain the details of their action.

(1) *Variation of moisture.*—It has been observed that the alternate drying and wetting of a fine-textured soil is favorable to the production of the crumb structure. The greater the number of times a soil changes from one condition to the other the smaller is the size of the granules when other conditions are uniform. Continued wetness or continued dryness does not favor the crumb structure.

(2) *Freezing.*—In the freezing of wet soils, the water forms crystals in the larger, open spaces between the soil particles, and the soil mass is broken up or separated, resulting in a condition favoring the granular structure.

(3) *Cultivation.*—Manipulation of the soil by plowing or other forms of tillage, when the moisture content is not too great or too small, favors the formation of the granular structure. On the other hand, tillage of the soil when it is too wet or too dry is unfavorable to the crumb-like structure.

(4) *Presence of organic matter.*—The presence of decomposing organic matter in soils favorably affects the soil structure (p. 135).

(5) *Growth of roots.*—It is a matter of common observation among farmers that crops differ in their effects upon soil structure. Plants with fine roots, like grass, wheat, etc., leave the soil in better working condition or tilth than coarse-rooted plants.

(6) *Soluble salts.*—Certain compounds like calcium hydroxide (slaked lime), calcium sulphate (gypsum), calcium carbonate, mineral acids, common salt, etc., have the power of causing fine particles to unite and form aggregations. For example, if fine clay is mixed with water to form a turbid mixture and left to itself, it may remain turbid several days before the finest particles settle to the bottom and leave the water clear. If, however,

we put into the mixture a little calcium oxide, which at once forms hydroxide (p. 54), or add hydroxide directly, the fine particles in suspension are quickly affected. First, the particles come together and form little flakes or floccules and these soon settle, leaving the liquid clear. This process is known as *flocculation*, from the formation of the characteristic little flakes or floccules. Calcium carbonate being less soluble than the hydroxide has much less flocculating power. This action is one of practical importance in connection with fine-textured soils, because it favors the granular structure. This is one of the important effects of liming (p. 379) clay soils.

Some substances, on the other hand, produce just the opposite effect, known as *deflocculation;* they break up the crumb structure, causing the grains to separate, or they prevent the formation of the crumb structure. Among such deflocculating compounds are sodium carbonate and potassium carbonate (p. 51), which are found in many alkali soils. Long-continued use of nitrate of soda (p. 438) on clay soils may result in the formation of sodium carbonate in amounts sufficient to cause deflocculation.

(7) *Animal life.*—The soil crumbs formed by the action of earthworms are familiar. Ants and animals with burrowing habits also influence soil structure.

(8) *Hard rains.*—The effect of driving, heavy rains is readily seen on the surface of a cultivated clay soil. The granular structure is destroyed, and when the surface dries, a crust is formed which affects seriously the properties of the soil in relation to the growth of plant-roots. These unfavorable effects are prevented by any kind of covering that protects the soil, such as mulches, sod, etc.

CHAPTER VII

THE INORGANIC CONSTITUENTS OF SOILS

In the previous chapter we have discussed soils with reference to their physical structure and properties, and it now remains to study them with reference to the chemical elements and compounds that enter into their composition, especially those that are of importance in connection with the feeding of plants and also those that affect prominently the physical properties of soils.

All agricultural soils contain two general classes of constituents, (1) mineral or inorganic and (2) organic. The inorganic part comes from the rocks of the earth's crust; the organic portion has its origin in vegetable and animal matter. The inorganic soil constituents we will consider in this chapter and the organic in the chapter following.

Composition of earth's crust.—We can obtain an approximate idea of the general composition of soils by noticing the average composition of the earth's superficial crust, the material which enters most largely into soils; this is approximately as given in the following table:

TABLE 18—CONSTITUENTS OF EARTH'S CRUST

Element	Per cent.	Element	Per cent.
Oxygen	47.0	Magnesium	2.6
Silicon	28.1	Sodium	2.6
Aluminum	8.2	Potassium	2.3
Iron	4.6	Sulphur, phosphorus and other constituents	1.1
Calcium	3.5		

In general, it is seen that the materials most abundant in rocks do not contribute any material to the nourishment of plants. Thus, oxygen, silicon and aluminum

make up over 83 per cent. of the rock constituents from which soils are formed.

Mineral compounds in soils.—When rocks are converted into soil, those portions that undergo chemical change generally form certain definite chemical compounds and then cease to change farther to any marked extent under the conditions present. The following arrangement shows in general the different kinds of chemical compounds (pp. 31-36) which are more or less commonly present in soils:

TABLE 19—CHEMICAL COMPOUNDS IN SOILS

Name of element	Forms of combination
Calcium	Carbonate, sulphate, silicate, phosphate, nitrate
Potassium	Carbonate, sulphate, silicate, phosphate, nitrate, chloride
Sodium.........	Carbonate, sulphate, silicate, phosphate, nitrate, chloride
Magnesium	Carbonate, sulphate, silicate, phosphate, nitrate, chloride
Iron	Oxide, hydroxide, hydrated oxides, phosphate, silicate
Aluminum	Oxide, hydroxide, hydrated oxides, phosphate, silicate
Manganese	Oxide, hydroxide, hydrated oxides, phosphate, silicate

Some of these compounds are present in soils only under exceptional or abnormal conditions; others are always present in all agricultural soils. We shall consider in detail only the more important of those compounds which for any reason are of special interest in connection with the growing of crops. The points deserving of special attention are the special kinds of compounds, the amounts present in soils, the ways in which they may be removed from the soil and their special action on other soil constituents or on the soil as a whole.

(1) *Calcium.*—(a) Compounds. The most important calcium compound in soils is the carbonate ($CaCO_3$), in which form it is present in all good agricultural soils to a larger extent than in any other form of combination. It is generally present, but to a much less extent, as phosphate, nitrate, sulphate and also in some of the complex silicates (pp. 52-55). The carbonate may be regarded

as the commonly available form or source of plant-food calcium; in most silicates calcium is of little importance as an immediate source of plant-food, although pure calcium silicate ($CaSiO_3$) is regarded as furnishing available calcium.

(b) Amount in soils. Calcium carbonate is present in most soils, but in very variable amounts, ranging from a fraction of 1 per cent. to over 50 per cent. in some limestone soils. Soils are not capable of raising good crops when the calcium carbonate drops below 0.2 per cent. and in most cases an amount in excess of 1 per cent. (equal to 30,000 pounds per acre in the upper foot of soil) is considered desirable. Coarse sands and soils with very high percentages of organic matter, such as muck and peat soils, usually contain insignificant amounts of calcium carbonate; clay soils also are commonly deficient. The subsoil may often contain less than the soil. *Marly soils* are mixtures of clay and finely divided calcium carbonate. *Shell-marl* is sometimes found in deposits consisting of nearly pure calcium carbonate, but it is generally mixed with varying amounts of impurities. In alkali soils calcium compounds are present in considerable amounts, especially the sulphate; the chloride may be present also.

(c) Removal. The calcium carbonate in soils is constantly undergoing solution by the carbon dioxide present in soil water, also by acids formed in the decomposition of organic matter (p. 125), and in this dissolved form it may escape from the soil in the drainage water (p. 185); calcium is also removed by crops (p. 78) in rather large amounts, varying in the case of different kinds of plants. On account of the important relations of calcium carbonate to soils and to plant growth, it is essential that the amount present be not allowed to diminish much below 1 per cent. This involves the occasional addition of calcium compounds to cultivated soils (pp. 363-390).

(d) Relation to texture. Calcium carbonate in soils may exist in particles of any size, varying from the texture of clay to that of sand. The finer the particles, the more quickly they undergo solution in water containing carbon dioxide.

(e) Action in soil. Calcium carbonate acts in several different ways, which are of great value in agricultural soils. (1) It neutralizes the acids in soils. In the decay of vegetable matter, acids are formed (p. 126), which accumulate in the absence of calcium carbonate and injure the crop-producing power of the soil. When calcium carbonate is present in abundance, the calcium unites with the acids, forming neutral, harmless salts. Calcium carbonate is the most effective acid neutralizer we find in soils. (2) Calcium carbonate changes the insoluble aluminum and iron phosphates into the more available form of tri-calcium phosphate (p. 45). In many soils containing insufficient amounts of calcium carbonate, the soluble phosphate applied in fertilizers is largely changed into the unavailable iron and aluminum phosphates and so practically lost to the immediate use of crops. (3) Soluble calcium carbonate (calcium carbonate dissolved in carbonated water) may replace potassium in some insoluble silicates, the calcium taking the place of the potassium in the insoluble silicate and the potassium changing to the soluble form of carbonate, an available form of plant-food. (4) The action of soluble calcium compounds upon soil structure in causing the flocculation of fine clay particles has been noticed already (p. 104). (5) After calcium carbonate is changed into soluble carbonate in the soil water, it is often redeposited under certain conditions in solid form and acts as a cement in holding together the finer particles of silt and clay, thus changing the structure of the soil particles favorably.

(2) *Potassium.*—(a) Compounds. Potash is present in

soils in both soluble and insoluble compounds. The soluble forms include sulphate, chloride (muriate), nitrate, and probably phosphate and carbonate. The insoluble forms are generally silicate compounds present in such minerals as potassium or orthoclase feldspar containing about 14 per cent. of potassium, leucite containing about 18 per cent. of potassium (p. 52) and several others. In ordinary soil analysis, the percentage of potassium given is the acid-soluble, which roughly represents the amount available, but which is usually only a small part of the total potassium present.

(b) Amount in soils. Potassium is present in soils in very variable amounts, ranging from a few hundredths of 1 per cent. to 3 per cent. or more, only a small proportion of which is generally available. A good agricultural soil does not generally contain less than 0.2 per cent. of acid-soluble potassium (equal to about 6,000 pounds per acre in the upper foot). Potassium is generally abundant in clay soils and deficient in muck, peat and sandy soils. In alkali soils potassium is often very abundant, running in some cases as high as 17 per cent. in the upper 12 inches, though it is usually between 1 and 7 per cent.; in these soils it exists in the forms of sulphate, carbonate and chloride.

(c) Removal. Potassium compounds, even the soluble forms, are not readily removed from soils by drainage water (p. 184). The chief methods by which potassium is taken from soils is by means of crops (p. 177).

(d) Relation to texture. Generally speaking, potassium is found in largest amounts in the finer soil particles.

(e) Action in soils. In the presence of large amounts of calcium carbonate in the soil, some potassium carbonate may be formed by interaction of calcium and potassium salts. It is not probable that enough potassium carbonate is formed, unless under rare conditions, to affect

unfavorably the crumb structure in the case of most agricultural soils. When potassium carbonate is present in soils, it is apt to unite with the nitric acid produced by nitrification (p. 205) to form potassium nitrate. The insoluble potassium in silicates is changed, under favorable conditions, into soluble forms by the action of salts of calcium, sodium and magnesium as well as by the action of micro-organisms (p. 228).

(3) *Sodium* is present in the soil in combinations much like those of potassium. It is generally present in smaller amounts than potassium. Sodium compounds are prominent, and often predominant, constituents of alkali soils. The compounds present in such soils are one or more of the following: Sulphate, carbonate, bicarbonate, chloride, nitrate and phosphate. While of little importance as plant-food (p. 84), sodium compounds take part in chemical changes in the soil which are of value. For example, sodium in its soluble compounds may take the place of potassium in insoluble compounds, changing the potassium from an unavailable into an available compound. Some sodium compounds may be useful in the process of nitrification (p. 209). In the case of excessive use of sodium nitrate in the absence of acid-forming compounds, amounts of sodium carbonate may be formed to such an extent as to injure seriously the crumb structure of soils (p. 438). The amount of sodium does not appear to vary much in different-textured particles.

(4) *Magnesium* is usually present in soils in much the same forms of combination as calcium, but generally in much smaller amounts. Soluble magnesium compounds are believed to be injurious to plants when present in amounts nearly equal to calcium. The sulphate and chloride of magnesium are often prominent constituents of alkali soils. These compounds are poisonous to plants even in comparatively small amounts, especially if the

amount of calcium compounds is relatively deficient. The action of magnesium compounds in soils is somewhat the same as the corresponding calcium compounds in neutralizing acids, in effect on insoluble aluminum and iron phosphates, and in making insoluble potassium available. Magnesium is removed from the soil in much less amounts than calcium, either by drainage water or crops. The amount of magnesium is greatest in the finest particles, decreasing with coarseness of texture.

(5) *Iron* is more or less prominently present in soils in the form of hydroxide (FeH_3O_3), and oxide (Fe_2O_3) and in forms called hydrated oxides, which are intermediate in composition between hydroxides and oxides; these forms are familiar under the general term of iron rust. These compounds are red, yellow or brown and form the main coloring matter of soils. These are generally products of decomposition of complex silicates containing iron, which undergo chemical change when air has abundant access to moist soils. In some cases, as in clay subsoils, in soils very rich in iron compounds, in muck-beds, etc., where air is largely excluded, compounds of iron are formed which are poisonous to plants and which, if present in certain amounts, make a soil sterile; for example, sulphur compounds of iron known as sulphides may be changed into the injurious compounds, iron sulphate (p. 57) and free sulphuric acid. This condition can be usually prevented or overcome by generous use of calcium carbonate or quicklime (p. 375). The amount of iron compounds present in soils varies greatly, but the cases are extremely rare in which a soil does not contain enough iron to supply the needs of crops indefinitely. The amount of iron removed from soils by drainage water or crops is generally less than that of any other soil constituent. Iron compounds may be useful in forming insoluble iron phosphate and thus preventing risk of loss of phosphorus by drainage. Iron

compounds, like those of calcium, may act as cementing material in holding together smaller particles of silt or clay. The amount of iron is greatest in the finest soil particles and diminishes as the particles increase in size.

(6) *Aluminum* is present in soils chiefly as silicate, hydrated oxide, and phosphate. It is especially prominent in soils derived from clay (kaolinite); it is present in largest amounts in the particles of finest texture, diminishing as the texture of the particles increases. Some of the hydrated silicates and oxides of aluminum are believed to exercise some strong influence in holding some of the plant-food elements in the soil, preventing their loss in drainage water (p. 183). Any value which aluminum may possess in crop growing is confined to its action on other soil constituents.

(7) *Silicon* is present in soils in much larger amounts than any of the preceding constituents. Silicon and oxygen make up about 75 per cent. of the mineral compounds present in soils. Silicon occurs as the characteristic constituent of all silicates. It is also present in soils to a variable extent as silicon dioxide (SiO_2), commonly called silica, which is familiar as the mineral, quartz. White quartz sand consists of silica and in all sandy soils silica is a prominent constituent. What is known as "soluble silica" is present in largest amounts in the smallest-sized soil particles, the larger particles containing less. In some cases soluble silica acts as cementing material in binding together the small soil particles.

(8) *Phosphorus* is present in soils in smaller amounts than any of the elements we have thus far discussed. A soil containing 0.25 per cent. of total phosphorus (equal to 7,500 pounds an acre in the upper foot of soil) is very rich in this constituent; the usual amounts in agricultural soils lie between 0.03 and 0.11 per cent., only a part of this being available. In the finer particles of soils, phosphorus compounds are present in larger amounts than

in coarser particles. Phosphorus is present in soils in the form of phosphoric acid compounds or phosphates, mainly as phosphates of calcium, iron, aluminum and magnesium. Iron and aluminum phosphates (p. 49) are so insoluble as to be practically unavailable plant-food; however, in these forms, they are not easily leached from soils. Insoluble or tri-calcium phosphate (p. 47) is a more readily available form. On soils containing large amounts of iron and aluminum compounds, the soluble phosphoric acid in fertilizers is changed into a form of

Experiments in which the application of phosphorus (P) compounds increases the yield, showing that the soils are lacking in this plant-food constituent. TEXAS STATION.

iron and aluminum phosphate unless there is considerable calcium carbonate in the soil. Phosphates are removed from soils by crops (p. 177) and, to some extent, by drainage water, though in much smaller amounts than any other important plant-food constituent.

(9) *Sulphur* is present in agricultural soils in the form of sulphate; in special cases, which may be regarded as abnormal, it may exist temporarily as sulphide. It is found in relatively small amounts in most soils but in proportions which are large in comparison with the

amounts called for as plant-food. It is a prominent constituent of alkali soils in combination as sulphate of potassium, sodium, magnesium and calcium sulphate. Sulphates are found in considerable amounts in drainage water, and it is conceivable that in some cases a soil might become deficient. However, when commercial fertilizers are applied in the form of potassium sulphate, or acid phosphate, which may be about half calcium sulphate (p. 271), considerable amounts of sulphate are added to the soil.

AMOUNTS OF PLANT-FOOD CONSTITUENTS IN SOILS

In studying the results of chemical analysis of soils, we may use as an illustration the following analysis of a soil known to be good for crop production and therefore recognized as fertile:

Nitrogen	0.20 per cent.	
Phosphorus (P)	0.07 "	(equal to 0.16 per cent. phosphoric acid, P_2O_5)
Potassium (K)..	0.35 "	(" 0.42 " potash, K_2O)
Calcium (Ca)...	0.60 "	(" 1.50 " calcium, carbonate, $CaCO_3$)

An examination of these figures suggests the following statements:

(1st) The soil constituents that plants use for food are present in soils only in relatively small proportions, the great bulk consisting of such inert materials as compounds of silica, aluminum, etc.

(2d) The combined amounts of nitrogen, phosphorus and potassium, even in very fertile soils, are usually less than 1 per cent.

(3d) Although the figures above do not furnish the information, it is true that, of the plant-food compounds in soils, only very small amounts are in forms immediately available.

Variation of plant-food constituents in agricultural soils.—In examining the results of analysis of large num-

bers of crop-producing soils, it will be found that the proportion of each plant-food constituent varies widely in different soils. It is desirable to state the results of soil analysis not only in the form of percentages but also as pounds per acre. In analyzing soils, samples are taken to a certain depth, which varies, but is usually 6, 9 or 12 inches. The samples taken to a depth of 6 or 7 inches represent the portion usually plowed, in which the bulk of roots grows. At depths of 9 or 12 inches portions of soil are included in which plant-roots penetrate more or less and the analysis of which gives an idea of the amount of plant-food near enough at hand to be utilized easily. In stating the results of soil analysis, it is necessary, therefore, to state the depth to which the sample of soil is taken; this is particularly important in stating the results as pounds per acre. It will suffice for our purpose to give results based on a depth of 9 inches, assuming that the soil in one acre to that depth weighs, on an average, 2,500,000 pounds. In soils of good crop-producing power, the amounts of constituents usually lie between the limits indicated in the following table:

TABLE 20—PROPORTIONS OF TOTAL PLANT-FOOD CONSTITUENTS IN AGRICULTURAL SOILS

Constituent	Per cent	Pounds in one acre to depth of 9 inches
Nitrogen	0.10 to 0.30	2,500 to 7,500
Phosphorus (P)..	0.03 to 0.11 (=0.07 to 0.25 phosphoric acid, P_2O_5)	750 to 2,750 (1,750 to 6,250, P_2O_5)
Potassium (K)...	0.8 to 1.60 (1.00 to 2.00 potash K_2O)	20,000 to 40,000 (25,000 to 50,000, K_2O)
Calcium (Ca)....	0.20 to 1.50 (0.50 to 3.75 calcium carbonate, $CaCO_3$)	5000 to 37,500 (12,500 to 93,750, $CaCO_3$)

In extreme cases, figures run below and much above these. Thus, potassium may in some cases run above 100,000 pounds an acre and calcium still higher, while

phosphorus may exceed 10,000 pounds, and nitrogen in muck and peat soils may run above 50,000 pounds per acre.

Relation of food-supplies to needs of crops.—When we take into consideration the fact that few crops use annually more than 50 to 75 pounds of nitrogen, 10 to 20 pounds of phosphorus (23 to 46 pounds of phosphoric acid), 75 to 100 pounds of potassium (90 to 120 pounds of potash), it is obvious that even a rather poor soil contains each of these constituents in amounts sufficient to supply crops for many years.

CHAPTER VIII

THE ORGANIC CONSTITUENTS OF SOILS

In addition to inorganic, rock-derived materials, soils contain variable amounts of organic matter, which has its origin for the most part in the former generations of plants that have grown in the soil and undergone decomposition; to a less extent, soil organic matter comes also from animal remains. In the case of agricultural soils, the upper layer is continually receiving supplies of organic matter in the form of leaves, plant residues left in the soil (roots, stubble, etc.), green-crop manures (pp. 348-362), farm manures (pp. 288-347) and various kinds of vegetable and animal waste materials. This organic matter, whatever its original source or character, is found in soils in all kinds of conditions or stages of decomposition, varying from the fresh material to that which has undergone more or less extensive chemical changes, and which appears in the forms known as leaf-mold, peat, muck, humus, vegetable mold, etc., according to the nature and extent of the changes that have occurred in it. Sooner or later, decomposition so alters vegetable or animal matter in soils as to form a dark-colored mass, in which all trace of any characteristic tissue structure in the original material disappears, and the decomposed material is more or less completely incorporated as an integral part of the soil mass; in this condition, the soil organic matter is called *humus*.

The presence of decomposing and decomposed organic matter in agricultural soils is essential, generally speaking, as an aid in furnishing conditions which enable crops to use applied fertilizers most efficiently. The organic matter of soils may affect the production of crops in more

ways than any other soil constituent, because, as we shall show later in more detail, (1) it is a source of plant-food, (2) it helps to make available some of the insoluble mineral plant-food, and (3) it influences favorably the physical conditions of soils. (4) It may also, on the other hand, contain compounds which under some conditions are poisonous to plants.

On account of the extreme importance of organic soil constituents, we shall study (1) the changes that organic matter undergoes in soils, (2) the conditions influencing such changes, (3) the relations of the decomposition products to other soil constituents, (4) the specific action in relation to the use of fertilizers, and (5) soil acidity.

Alfalfa roots go deep into the soil and furnish a large amount of organic matter. KANSAS STATION.

Composition of organic matter.—The composition of organic matter, whether fresh or in various stages of decomposition, is extremely variable, since it is a complex mixture of numerous compounds, the kinds and amounts of which constantly vary. In general, the decomposition products of organic matter are governed by the source and character of the original material and by the conditions determining the kind and extent of decomposition, such as

moisture, air supply, temperature, kind of micro-organisms and mineral constituents, factors which, in turn, are affected by tillage, drainage, fertilization, irrigation, inoculation, etc.

Without going into too great detail, it is desirable that we state a few fundamental facts regarding the composition of fresh organic matter and then trace the general changes through which the compounds of the fresh material go during the processes of decomposition.

Fresh organic matter is made up, for the most part, of three general classes of compounds: (1) *Nitrogen-free organic compounds* (consisting of carbon, hydrogen and oxygen), which include (a) carbohydrates, consisting of cellulose (the chief constituent of cell-walls), sugar, starch, etc., (b) fats or oils and waxes, and (c) organic acids. (2) *Nitrogen-containing compounds,* mostly proteins (containing nitrogen, usually sulphur, and, in some cases, phosphorus, in addition to carbon, hydrogen and oxygen). (3) *Inorganic* or *mineral constituents.* For our purpose, we do not need to consider numerous other compounds which are present in small amounts. These three classes of compounds in fresh organic matter undergo decomposition in soils and furnish variable complex mixtures, which may contain, among others, some or all of the following products of decomposition, according to the kind and extent of change.

(1) *Nitrogen-free compounds* make up the largest part of soil organic matter; they consist largely of various indefinite, little-understood, dark-colored substances, more or less acid in character, rich in carbon (so-called humic-acid compounds) and, in smaller amounts, of certain definite organic acids (acetic, butyric, etc.). These compounds come in largest amount from the cellulose, starch and sugar of fresh organic matter.

(2) *Nitrogen compounds* are present in decomposing and decomposed organic matter in much smaller amounts

than nitrogen-free products. They include (a) **dark-colored, insoluble nitrogen-containing carbon compounds,** (b) ammonia, and (c) nitric acid.

(3) *Inorganic compounds* include the mineral constituents or salts, mainly in the form of calcium, magnesium and potassium compounds, such as phosphate, carbonate, sulphate, etc., which are always present in small amounts in fresh organic matter.

Decomposition of organic matter in soils.—The process of decomposition by which fresh organic matter in soils is changed into entirely different forms of combination is a biochemical process primarily brought about by microorganisms, chief among which are bacteria (pp. 198-213) and fungi (p. 230). Decomposition is of two general kinds, one taking place in air (aërobic, p. 200) and the other away from the air (anaërobic, p. 201). The composition and amount of the products of decomposition remaining in the soil differ greatly in the two processes.

(1) *Decomposition in presence of air.*—With abundance of air, organic matter (consisting chiefly of carbon, hydrogen, nitrogen and oxygen) decomposes into simpler compounds, and practically all passes away, when the process is complete, in the form of gaseous compounds (carbon dioxide, ammonia, free nitrogen, water, etc.), without leaving any organic residue. This is illustrated when leaves or twigs fall upon the ground. Without darkening much, such organic materials, under favorable conditions of moisture and temperature (p. 200), undergo a process of slow burning or union with oxygen and in time disappear, leaving about the same constituents that would be found in the ashes produced by rapidly burning the same material. This process can be easily observed in its various stages in forests in the case of fallen trees; in the course of time, under the action of fungi and bacteria, the solid wood softens, becomes "rotten," loses all signs of structure of grain or fiber, and sinks down into

a shapeless heap; the material may remain nearly white in color or may become reddish or brownish. The pile slowly flattens out and all traces of organic matter disappear in time.

This destructive form of decomposition takes place to a greater or less extent in soils according to the amount of air present, other conditions being uniform. It is a fact of practical experience that vegetable or animal matter disappears much more rapidly in light, porous, well-drained, well-ventilated soils than in compact or over-moist soils where the air supply is limited (p. 132). Other conditions being the same, organic matter disappears more rapidly at higher temperatures, as illustrated in case of a warm, dry climate.

(2) *Decomposition in absence of air.*—Away from air, as when leaves or twigs fall into a swamp or pond and are buried under water, the organic matter decomposes slowly and only partially, leaving a comparatively large amount of incompletely decomposed organic material, since the loss of organic compounds through change into gaseous products is comparatively small. In connection with this process, the following facts are of interest:

(a) Visible effects of decomposition. Signs of change in the original organic material are made visibly evident, first, by change in the color of the substance through various shades of brown to black, and, second, by the loss of any characteristic shape or tissue structure that the material may have had originally, resulting in the formation of a finely granular or powdery mass when dry, or a gelatinous mass when wet.

(b) Increase of carbon and resistance to change. In the conversion of cellulose, starch, etc., into the dark-colored compounds constituting a large part of well-decomposed organic matter, hydrogen and oxygen pass from the organic matter in the form of gases in a much larger proportion than does carbon; consequently, the

carbon accumulates and the decomposed organic matter is richer in carbon and poorer in hydrogen and oxygen than the original organic material. It is also a fact of interest that these dark-colored, high-carbon compounds show increasing resistance to further decomposition, the resistance becoming more pronounced as the percentage of carbon in the substance increases. On this account the dark-colored material remains in the soil a long time. This resistance to decomposition probably finds an explanation in the composition of the material. The micro-organisms first use up the least resistant compounds of the fresh organic matter. In the remaining tougher portions, it is more difficult for the organisms to obtain food and their activity diminishes. In time, when only the most resistant compounds are left, decomposition practically ceases from lack of food supply. In this connection, it may be mentioned that cellulose is of different kinds, some easy, and some difficult, to decompose. For example, the soft parts of leaves decompose easily in comparison with the ribs and stems.

(c) Increase of nitrogen and insolubility. Proteins, in absence of air, are decomposed with greater difficulty and less completeness than starch, sugar, some forms of cellulose, etc. Nitrogen, therefore, tends to accumulate and the decomposed organic matter contains a larger percentage of nitrogen than the original material. The nitrogen compounds slowly change into dark-colored substances of variable composition and the nitrogen is left in forms of combination not easy to decompose further. More or less soluble nitrogen is made insoluble by being taken into the body substance of the micro-organisms themselves. In this anaërobic process of decomposition, nitrogen compounds tend to become less available as plant-food.

Intermediate decomposition products.—Intermediate between the fresh organic matter and the products of its

advanced decomposition, the decomposing material, as a whole, acquires certain characteristics, which represent the kind and extent of change, or the stage, in the process of decomposition. The mass of organic material in these intermediate stages of change is known under various names, such as leaf-mold, peat, muck, etc. The character of the products is largely controlled in each case by the conditions of air supply, temperature, moisture, etc., since these conditions determine what particular set of decomposing agents predominates. We will now briefly consider the main characteristics of some of these intermediate decomposition products of organic matter.

(1) *Leaf-mold* or *mild humus* is the name applied to the dark-colored, organic material formed by the incomplete decomposition of leaves, twigs, etc., on the surface of well-drained forest soils. Of a similar nature is the brown, powdery material often found inside of dead, hollow trees. Such materials represent a stage of decomposition, in the presence of air, intermediate between the fresh organic matter and the gaseous products formed by complete action. Leaf-mold and similar materials are quite different from what we call humus. This is shown in two ways: (1) Leaf-mold is either neutral or alkaline, while humus is acid; (2) leaf-mold is easily changed in air by micro-organisms into simple compounds, while humus is only slowly changed.

(2) *Peat* consists of plant remains in the early stages of decomposition under water and therefore away from the air. The original structure of the plant tissues is more or less plainly visible. Peat is generally formed in very extensive deposits, often of considerable depth. Decomposition is usually delayed or prevented by exclusion of air through saturation with water, but takes place when the mass dries out somewhat; consequently there are usually alternating periods of active decomposition and suspension of such changes. The partially decomposed

material may be prevented from undergoing further change by the accumulation of acid products of decomposition, which poison the micro-organisms. The alternate saturation and drying of the mass furnish conditions

The effect of $3.50 worth of potash per acre on a marsh soil. It would seem that a potash fertilizer should receive some consideration when an application of 150 pounds of potassium chloride will produce 15 tons of ensilage corn where only 3 tons would grow otherwise. WISCONSIN STATION.

which delay or advance decomposition. The plant-food material in peat is only slowly available. Two general classes of peat are recognized, (1) grass peat from swamp-grass, etc., and (2) moss-peat from sphagnum moss.

(3) *Muck*, known also as meadow-peat, swamp-muck, etc., consists of plant remains that have undergone more complete decomposition than in case of peat, though the line of division between muck and peat is not a sharp one. Muck more nearly approximates the condition of the dark constituents of humus. Muck is brown or black in color and shows much less of the original structure of plant tissues than does peat. The plant-food constituents in muck are not quickly available, but are more so than those of peat. Drainage, liming (p. 379), application of phosphorus and potassium compounds, and tillage are the means usually employed to make peat or muck soils productive.

Active and inactive organic matter.—In this connection, attention is called to a distinction that may be made in relation to organic matter in soils, as *active* and *inactive*. It is said to be active when its less resistant portions are undergoing decomposition, changing its own plant-food constituents from insoluble to soluble forms, and furnishing products that convert into available compounds some of the unavailable forms of plant-food material in the soil (p. 228). When the more active stages of decomposition have passed, the micro-organisms having used up the more easily decomposable organic constituents, there remains a portion which so strongly resists further change that it may require years for its complete decomposition, and this portion is known as inactive or slowly available organic matter. This inactive material, while not a source of quickly available plant-food, is extremely useful on account of its effect upon the physical properties of the soil (p. 134). The application of fresh organic matter to soils is generally attended with much more rapid and effective results than the use of such inactive materials as peat and muck.

Acids in decomposing organic matter.—In the decomposition of organic matter, acid compounds form a class

of constituents deserving special attention on account of their important, practical relations. For convenience, the acid compounds in decomposing and decomposed organic matter may be considered under the following heads: (1) Acids in plant juices, (2) organic acids from carbohydrates, fats, waxes, resins, etc., (3) miscellaneous organic acid compounds, (4) carbon dioxide, (5) nitric acid.

(1) *Acids in plant juices.*—Plant juices are generally acid owing to the presence of the organic acids or acid salts they contain, which are commonly spoken of as vegetable acids. These are present in the fresh organic matter and, although they are decomposed sooner or later, they probably persist long enough to produce some solvent effect in the soil.

(2) *Organic acids from carbohydrates, fats, waxes, resins, etc.*—In those portions of soils that are well aerated and warm, sugar, starch, part of the cellulose, oils, etc., are converted by micro-organisms quite rapidly into definite organic acids. It is a familiar experience that carbohydrate materials sour easily and oils become rancid. For example, one acid commonly formed by carbohydrate decomposition is acetic acid, familiar in vinegar, ensilage, fermenting pea-vines, fruit-refuse about canning works, etc. Many of the acids formed in this way are of definite, well-known composition. These acids or their salts may be decomposed into carbon dioxide and water in the presence of abundance of air and warmth, and, may, therefore, not be present in soil organic matter that has reached an advanced stage of decomposition under these conditions.

(3) *Miscellaneous organic acid compounds.*—There is present in the organic matter of the soil, when it is in an advanced stage of decomposition, a variable number of different organic compounds more or less acid in character. Not very much is known about these yet and

that little is the result of recent investigation. These acid compounds, as well as others of a quite different chemical character, are found in that part of the organic matter which it has been the custom to call "humic acid." This substance was supposed to be made up of a few well-defined compounds, but recent work appears to show that the old conception was based upon serious errors, due to the undeveloped state of knowledge in the field of organic chemistry, and that none of the supposed compounds actually exists, but that in their place there are a great many other organic compounds, some of which have acid properties, though very much remains to be learned about the composition of this complex substance or mixture of organic compounds. Under the former conception, "humic acid" unites with such elements as calcium, magnesium, potassium, etc., to form "humates."

Out of the mass of statements in regard to the properties of so-called "humic acid," it may be useful to remember one or two observations. When the compounds embraced under the term "humic acid" are treated with an alkali, such as ammonium, sodium, or potassium hydroxide, soluble compounds are formed; when these organic compounds are treated with a basic compound of an alkaline earth, like calcium or magnesium hydroxide or carbonate, insoluble compounds are formed. Therefore, in soils containing an abundance of calcium carbonate, the acid compounds are completely neutralized and there remain only compounds that are not easily soluble in water.

The presence of these uncombined or unneutralized acid organic compounds in an acid soil or in sour muck is indicated by the following test: Put about a tablespoonful of soil into a glass or cup half full of water, to which is added a teaspoonful or two of strong ammonia that has been diluted with four or five times as much

water. After standing several hours, the liquid becomes dark-brown or black if acid compounds are present in the soil. This dark solution is formed by the combination of ammonia with these organic compounds; these ammonia compounds dissolve in water and produce a dark color. When calcium carbonate is present in a soil, it combines with these organic acid compounds and the resulting compounds are not soluble in ammonia. When there is a deficiency of calcium compounds, the organic acid compounds remain uncombined and can then combine with ammonia to form dark solutions. This is really a test for deficiency of lime. It is somewhat the same kind of material that imparts the dark color to liquid draining from a manure pile. The dark color of water in muck swamps, or in ponds or lakes surrounded by wooded hills, or in streams confined to forests, is due to the presence of organic decomposition products of vegetable matter leached from the soil, which is rich in organic decomposition compounds. The addition of some calcium compound to such dark solutions forms a precipitate, separating from the solution in dark, flaky masses and leaving the liquid clear and colorless.

(4) *Carbon dioxide gas* is always formed (p. 60) by the decomposition of organic matter in soils; it is taken up by the soil water and largely retained. Soils in which considerable amounts of organic matter are undergoing decomposition are rich in this gas, the soil air often containing two or three hundred times as much carbon dioxide as does ordinary air.

(5) *Nitric acid* is produced as the final product of the bacterial change (p. 204) of the protein compounds that are present in fresh organic matter.

Poisonous compounds or toxins formed from organic matter.—At the Bureau of Soils (U. S. Dept. of Agr.), there have been recently isolated from the organic matter of soils numerous organic compounds that are decompo-

sition products of organic materials. Among these compounds are some that appear to be useful plant-foods, while some act as poisons, or are toxic, to plants grown in water solutions containing these compounds in very small amounts. It is thought that to some ex-

Effect of a soil toxin upon the growth of wheat seedlings. The smaller plant (1) was grown in a culture solution containing 200 parts per million of di-hydroxy-stearic acid; the larger plant (2) was grown in distilled water. BUREAU OF SOILS, U. S. DEPT. OF AGR.

tent plants may produce excretory products which are passed from the surface of roots into the soil and which are either directly poisonous or are changed in the soil to plant toxins. Experimental evidence indicates that soils and soil water may contain organic substances

that are harmful to the plant or organism producing them, and they may be harmful, neutral or even beneficial to other plants or organisms. To what extent the results of experimental work done by the growing of plants in water solutions in the presence of toxic substances can be applied to the action of these substances under actual soil conditions has not yet been demonstrated in a complete and extensive manner. So far as indications point at present, organic toxic compounds in the soil are rendered partially or completely harmless to plants by good drainage, aeration, tillage, crop rotation, liming and fertilizers, just the conditions that have been recognized as essential to good farming. The extent to which organic soil toxins constitute a factor of decreased power of crop production is a matter of dispute. By some it is regarded as the chief factor of unproductiveness, while others go to the extreme of denying that it is a factor of any serious importance at all. It can, however, be said safely that the work done in this field is extremely interesting and suggestive, but that it is still far from complete, and that it is too early to make far-reaching applications of the results now at hand to practical soil management. The existence of soil toxins appears to offer a satisfactory explanation of the decreased yields obtained by growing the same crop continuously upon the same soil; since it is held either that some plants excrete from their roots organic compounds that are injurious to themselves, though neutral or even beneficial to other plants, or that the decomposition of the soil residue of one crop produces compounds that are poisonous to the same kind of plants.

Action of organic matter on soil constituents.—Under agricultural conditions, vegetable or animal matter is distributed through the soil and comes into intimate contact with many of the soil particles. The composition of these particles is to some extent modified during the

process of decomposition of the organic matter, especially by the acid compounds present at various stages. The chemical changes produced in soil constituents by these acids may be summarized as follows:

(1) *Potassium compounds* in some insoluble forms are changed into soluble compounds, such as potassium carbonate, potassium nitrate, and combinations of potassium with organic compounds.

(2) *Phosphorus compounds,* especially insoluble calcium phosphate, are changed into soluble form. It is probable that even the insoluble iron and aluminum phosphates may be dissolved to some extent.

(3) *Organic acid compounds* combine with calcium, magnesium, etc., to form insoluble compounds, as already stated; this has the effect of preventing rapid loss of the decomposed organic matter by leaching.

(4) *Nitric acid* combines with calcium, potassium, sodium, etc., to form nitrates.

(5) *Carbonates.*—The carbon dioxide of the soil, which comes largely from the decomposition of organic matter, is effective by its solution in soil water in dissolving insoluble soil constituents and making them available, important among which are calcium carbonate and phosphate, and compounds of potassium, magnesium, etc.

(6) *Neutralization of acids.*—In combining with acid compounds in organic matter, the inorganic constituents of the soil usually form neutral salts; the free acids originally in fresh organic matter and those produced during decomposition are thus neutralized and the soil is prevented from becoming acid.

From the foregoing statements, it is readily seen that *the available supply of plant-food in soils is closely associated with the presence and decomposition of organic matter.*

Animal and vegetable matter in relation to composition of soil organic matter.—There are marked differences in the kinds and amounts of compounds formed by the

decomposition of animal, as comparea with vegetable matter, in soils. These differences are interesting and have commonly been overlooked in this connection. Vegetable matter contains carbohydrates in largest proportions and only small amounts of proteins, while the reverse is true of animal matter. In the decomposition of vegetable matter, relatively large amounts of organic acids are formed and the humus is distinctly acid. In the decomposition of animal matter, the products formed after the preliminary changes are compounds which become increasingly alkaline, instead of acid, until the strongly alkaline ammonia is finally formed. In the subsequent changes nitric acid is formed which is apt to be used up rapidly by growing crops and is therefore not liable to increase more than temporarily the soil acidity. It is, then, not inaccurate to speak of vegetable matter as a source of acid products and of animal matter as a source of alkaline products. Nitric acid is a strong dissolving agent, making available insoluble phosphorus and potassium compounds, and the salts of nitric acid (nitrates) act directly as plant-food. Organic acids produced by the decomposition of carbohydrates are not regarded as plant-food, and their dissolving power is somewhat weaker than that of nitric acid. In addition to the differences already mentioned, vegetable matter furnishes much larger amounts of insoluble, long-lasting organic material rich in carbon than animal matter does.

Relation of character of soils to decomposition of organic matter.—The rapidity with which organic matter is decomposed and the length of time the products remain in soils are points closely associated with soil conditions. In warm, light, porous soils, which easily admit abundance of air, the fresh organic matter is more rapidly decomposed and with greater loss than in compact, cold, moist soils, which are not well ventilated. In the case of more compact soils, decomposition is slower and con-

tinues longer. On account of less free admission of air, organic matter is more abundant in pastures and meadows than in cultivated soils.

Physical characteristics of decomposition products.—Decomposed organic matter (humus) in soils has certain characteristic physical properties which give it peculiar value in relation to crop production. Those of special interest are (1) absorbing power, (2) expansive nature, (3) lightness, (4) cementing power.

(1) *Absorbing power.*—Decomposed organic matter acts much like fine charcoal or a sponge in absorbing and retaining water, gases and solutions. For example, a cubic foot of soil rich in such material can hold twice as much water as the same amount of sand.

(2) *Expansive power.*—Decomposed organic matter shrinks very much in bulk when dried and expands similarly when it takes up water.

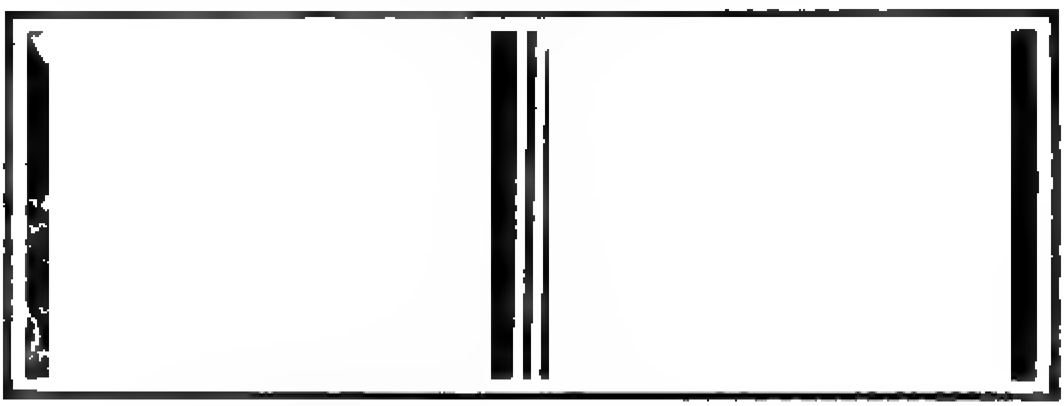
(3) *Lightness.*—A given volume of the organic portion of the soil averages about half as heavy as an equal volume of the mineral portion.

(4) *Cementing power.*—Though much less sticky than clay, decomposed organic matter is enough so to possess moderate cementing power; it holds together the coarse particles of light sandy soils, and it also separates the crumbs in clay soils, thus favoring the granular structure and promoting lightness.

Amount of organic matter in soils.—The amount of organic matter in soils varies widely. It is generally larger in the soil than in the subsoil, decreasing with depth; it is usually greater in clay than in sandy soils, and in meadows or pastures than in cultivated soils; it is generally greater in moist than in dry soils. In good soils where rainfall is fairly abundant, it averages about 2 per cent., varying from below 1 to over 5 per cent. In deep peat or muck soils that are acid, the amount of organic matter may rise as high as 85 per cent. In

soils of dry climates, it is usually below 1 per cent.; it is an interesting fact in connection with such soils that, while the amount of humus is small, the percentage of nitrogen in the humus is high, since the carbon in the organic matter is largely destroyed by fermentation under the conditions of high temperature and low moisture while the nitrogen is largely retained.

Action of organic matter in soils.—Organic matter is of extreme importance in connection with crop growing on account of the useful effects it produces in soils, some of which are purely physical, some chemical, and some



Corn following alfalfa. The soil is well filled with organic matter and is crumbly in structure.

Continuous growth of corn. The soil is compact, owing to lack of organic matter.

MINNESOTA STATION

biological. These effects, some of which have been already mentioned, are briefly summarized as follows:

(1) *Water-holding power.*—Organic matter in the form of humus increases the power of a soil to take up and retain water. On account of its sponge-like porosity, it absorbs water and gases (ammonia, carbon dioxide, etc.) much more abundantly than any other soil constituent. In holding water, it carries also those plant-food constituents that are dissolved in the water. Soils with a generous supply of decomposed organic matter resist the effects of drouth more readily.

(2) *Structure.*—Organic matter as humus greatly improves the mechanical condition of soils. In the case of heavy soils, it promotes the formation of the desirable crumb-like structure, making them less sticky and easier to work, enabling them to receive, distribute and hold water more effectively, improving ventilation, and making it easier for roots to penetrate the soil. In the case of sandy soils, it serves to bind together the loose soil particles, diminishing excessive porosity and ventilation, enabling them to take up and retain moisture, preventing abnormal leaching of plant-food, helping roots to get a firmer hold, and preventing or lessening drifting by winds or erosion by rains.

(3) *Warmth.*—The warmth of a soil is largely dependent upon the color. Other conditions being uniform, the darker a soil, the more readily it absorbs the sun's heat. Soils well supplied with decomposed organic matter are darker in color and therefore warmer; such soils maintain a more uniform temperature. This is of special advantage when an early start is desired in a crop, as in early market gardening.

(4) *Availability of mineral plant-food.*—We have already seen that the decomposition of organic matter in the process of decomposition produces acid compounds which are able to dissolve some of the mineral constituents of the soil, thus changing unavailable into available forms of plant-food. This action is of special value in relation to potassium and phosphorus compounds, the available forms of which are for the most part associated with the organic matter.

(5) *Relation to soil nitrogen.*—Most of the soil's nitrogen comes from the organic material. Therefore, the nitrogen in organic matter constitutes the main, natural source of the soil's nitrogen supply. The nitrogen decomposed in organic matter is held in slowly available form,

gradually undergoing conversion into nitrate under normal soil conditions.

(6) *Relation to micro-organisms.*—Organic matter is the soil material in which take place all the important activities of micro-organisms, because its substance furnishes the food essential to their growth. Other conditions being uniform, the greater the amount of organic matter in soils, the greater the work of micro-organisms. Its effect upon the moisture and temperature of soils makes the conditions more favorable for the growth of micro-organisms. Material like farm manure not only furnishes food for bacteria, but adds new supplies of micro-organisms to those already in the soil. Such materials as green-crop manures and ordinary organic fertilizing materials (cottonseed-meal, tobacco waste, tankage, etc.) are valuable more for the food they furnish bacteria already in the soil than for the numbers of bacteria they add.

Loss of organic matter in soils.—It is a well-known fact in farm experience that soils lose their organic matter. The effects of this loss are shown in various ways, as by increased compactness, decreased power to receive and hold moisture, greater difficulty of working and in diminished productivity. Generally speaking, any condition which is favorable to increased action of the destructive micro-organisms that work in the presence of abundance of air (p. 120) hastens the disappearance of soil organic matter, especially when such conditions are accompanied by a failure to furnish fresh supplies of organic matter. Among the specific conditions that favor rapid destruction and disappearance of soil organic matter we mention the following:

(1) *Abundance of air.*—In very porous soils where air penetrates freely, destructive fermentation of organic matter is marked, especially when accompanied with high temperature and moderate moisture. When green-crop manures are plowed under there is often danger that

they may not be sufficiently covered with soil or properly compacted, especially when the growth of organic material is very large; under such conditions destructive fermentation may destroy large amounts of it.

(2) *Moderate amount of soil moisture.*—Destructive fermentation is prevented in a wet soil on account of the exclusion of air. The presence of only a moderate amount of moisture favors action of micro-organisms.

(3) *High temperature.*—Temperatures above 75° F. favor rapid action of the decomposition organisms in soils. Organic matter is used up more rapidly in warm climates than in cool. In temperate climates, summer, of course, is the time when fresh organic matter is most rapidly transformed into humus.

(4) *Too much cultivation.*—This has the effect of making the conditions of air-supply and moisture favorable for the rapid decomposition of organic matter.

(5) *Supply of micro-organisms.*—When a soil contains large supplies of the micro-organisms that decompose organic matter, fermentation goes on more rapidly than when the supply is small. It is well known that green-crop manures, which add only small numbers of bacteria to soils, undergo decomposition more rapidly if two or three tons of partially fermented farm manure are spread on the surface before plowing under, because the manure furnishes large numbers of the desired kinds of bacteria.

(6) *Abundance of calcium carbonate.*—In a soil well supplied with any basic compounds that neutralize acids, such as calcium carbonate or the hydroxide (slaked lime), the acids formed by decomposition are neutralized as fast as formed and the decomposing organic matter is kept neutral. Under these conditions, no free acids accumulate to poison the organisms causing decomposition and they continue their work unimpeded; the organic matter is decomposed more rapidly than in soils containing little

or no basic or neutralizing material, where acids accumulate quickly and retard or stop the decomposition.

(7) *Lack of supply of organic matter.*—It is obvious that in a cultivated soil the organic matter must be exhausted in time, if no fresh supply is furnished. Failure to supply organic matter by the regular routine of crop-growing is due, first, to the removal of entire crops, leaving little or no organic material in the soil, and, second, to such kinds of crop-rotation as make no provision for supplying organic matter.

(8) *Summer-fallowing.*—The practice, once common, of allowing a field to lie bare for an entire crop season furnishes conditions of temperature and moisture which favor rapid destruction of organic matter with conversion of organic nitrogen into nitrate, which is in danger of loss by leaching before the soil is occupied by a crop.

Accumulation of organic matter in soils.—From the preceding statements in regard to the conditions under which organic matter is lost in soils, one can readily infer that the reverse conditions prevent its loss and favor its increase in soils. Generally speaking, those conditions favor retention of organic matter in soils which prevent or delay the process of decomposition, chief among them being exclusion of air and absence of warmth. Stated more in detail, the following conditions promote accumulation of organic matter in soils:

(1) *Limited air supply.*—The absence of air in slow fermentations of organic matter has already been discussed (p. 121).

(2) *Low temperature.*—The micro-organisms that decompose organic matter work more slowly as the temperature drops below 75° F.

(3) *Excessive supply of water.*—This has the effect of excluding air and keeping temperature low, thus preventing or delaying decomposition.

(4) *Absence of cultivation* has the effect of diminishing ir supply in the upper layer.

(5) *Absence of micro-organisms* causing decomposition necessarily prevents changes in organic matter in soils.

(6) *Lack of calcium carbonate* or other basic compounds permits the accumulation of organic acids which poison the micro-organisms and delay or prevent regular decomposition.

(7) *Addition of organic materials.*—The supply of organic matter in soils may be kept up by addition to soil of (a) green-crop manures, (b) crop residues (stubble, roots, etc.), (c) farm manure and waste materials, (d) organic matter in commercial forms, such as dried blood, cottonseed-meal, etc., (e) application of muck, peat, etc., (f) animal manure dropped in pastures.

Keeping up supply of organic matter in soils.—In considering the conditions under which organic matter is used up or is maintained in cultivated soils, it is obvious that the supply will not take care of itself, but must be given special attention. Speaking in general terms, there must be, in the first place, a sufficient supply of fresh organic material; then, the conditions of decomposition, especially as to supply of air and moisture, must be so regulated that the process will not, on the one hand, go on too rapidly and result in needless loss of organic material, or, on the other hand, proceed so slowly as to waste time in properly influencing the soil and crops; and, in addition, care must be taken by use of calcium carbonate to prevent an accumulation of acid products of decomposition to a degree that will unfavorably affect crops.

Relation of humus to use of fertilizers.—*Many thousands of tons of commercial fertilizers have been and are being applied without evidence of any appreciable effect upon yield or quality of crops, simply because used upon soils deficient in organic matter.* The reason is readily understood when we bear in mind the fact that absence or defi-

ciency of soil organic matter produces a set of physical, chemical and biological conditions, under which plants cannot grow to best advantage. Such a condition, for example, as compactness of soil, can be remedied, not by application of concentrated fertilizers, but only by a generous and wise supply of organic matter. In general, the use of commercial fertilizers on soils deficient in organic matter aggravates the abnormal conditions and does harm more often than benefit, resulting in direct financial loss.

SOIL ACIDITY

Before leaving the subject of soil composition, we will give more specific attention to the subject of soil acidity, in which there has been much interest within the past few years, but about which there is in the minds of many farmers, if not a wrong understanding, at least a lack of clear comprehension. In order to understand more definitely what is commonly meant by soil acidity, it is necessary to review very briefly some fundamental chemical facts relating to the constituents of soils.

Basic compounds.—Soils that produce satisfactory crops contain *basic compounds;* these are compounds that react chemically with acids to form neutral (non-acid) compounds known as salts (p. 31). Such basic compounds commonly present in soils include: (1) Carbonates, especially calcium (lime) carbonate, with some magnesium carbonate and lesser amounts of potassium and sodium carbonates, and sometimes iron carbonate; (2) the oxides and hydroxides, chiefly (p. 58) of iron and aluminum.

When acid compounds are added to or formed in soils, the basic compounds present in the soil combine with these acids and form neutral compounds called salts. When acid compounds accumulate in a soil to such an

extent as to neutralize all the basic compounds present, then the soil is in condition, with further increase of acids to contain free acid (p. 30), which is the mark of a distinctly "sour" soil.

It is obvious, therefore, that the liability of a soil to become acid depends upon: (1) The amount of basic (acid-neutralizing) compounds in the soil, and (2) the amounts of acid compounds added to or formed in the soil.

Non-basic compounds.—In addition to basic compounds, which are present in soils in very variable, but not usually in large, proportions, soils also contain large amounts of non-basic compounds, *which do not neutralize acids.* Such are (1) the silicates (p. 60), usually present in especially large proportions in most agricultural soils; (2) silica (silicon dioxide, SiO_2), the constituent characteristic of sandy soils; (3) all neutral salts, among which are the nitrates, chlorides and phosphates of calcium, magnesium, potassium, sodium and ammonium; and (4) all acid salts (p. 35), such as acid phosphates (p. 36) of calcium, potassium, etc. In soils containing only such compounds as do not neutralize acids, the accumulation of free acid can readily occur when other conditions are normal. Therefore, soils lacking in basic or acid-neutralizing compounds may be regarded practically as acid soils.

Harmful effects of absence of basic compounds.—The presence of free acids in soils, or a deficiency of basic compounds near the point of permitting the existence of free acids, is objectionable, especially for the following reasons: (1) The decomposition of organic matter in soils cannot take place normally in the absence of basic compounds (p. 29). (2) The formation of nitrate nitrogen from ammonia or organic nitrogen does not occur under acid conditions (p. 209). (3) The activity of bacteria in the utilization of atmospheric nitrogen in connection with

legumes is prevented by soil acidity (p. 221). (4) While some crops may flourish in the presence of acid compounds, many require a non-acid or neutral soil environment. (5) Basic compounds, like calcium carbonate, make possible those chemical changes in soils which result in the conversion of unavailable into available plant-food (p. 108) and which are impossible in soils lacking such basic compounds. (6) Basic compounds influence favorably those physical conditions that are essential in soils to the successful growth of crops.

Methods of testing soils for acidity.—Two direct and comparatively simple tests can be used in ascertaining whether a soil is acid, or what is the same thing, whether a soil is lacking in calcium carbonate. These two tests are the litmus test and the ammonia test.

(1) *Litmus test for soil acidity.*—Litmus paper that is either blue or neutral is turned red by acids, the intensity of color and quickness of change increasing with the concentration of acid. An alkali turns either red or neutral litmus to a blue color. When either blue or neutral litmus paper is turned red by a soil, the usual indication is that the soil is acid and does not contain much, if any, calcium carbonate. However, cases occur in which blue or neutral litmus paper is turned red by a soil, and yet applications of calcium carbonate or hydroxide do not bring better crops. This test has the advantage of being simple, rapid and in general, useful, even though its results, taken alone, cannot always be relied upon to tell when calcium is deficient in amount.

Litmus paper can be obtained at any drug-store in the form of strips. Only the best quality should be used. The paper should be kept in corked bottles to prevent change of color and should not be touched by the hands, which will usually turn the paper red. A pin or forceps should be used in handling litmus strips.

The test may be performed in different ways, but the following method has been recommended as giving the most reliable results: Take an ordinary, flat-bottomed glass tumbler and cut out round pieces of perfectly clean white blotting paper of just the size to fit closely in the bottom of the tumbler. Place the strip of litmus paper at the bottom of the tumbler, over this put the round piece of blotting paper, and then put in some of the soil to be tested. Add enough water to make the soil thoroughly wet and cover the glass with a saucer or other convenient dish. Prepare another tumbler in just the same way, except that no soil is added but only water; this is a blank or check test to show whether the water or the blotting paper used affects the litmus paper. These should be allowed to stand at least two hours; the color of the litmus paper against the clean white background can then be examined through the bottom of the glass without in any way disturbing the contents of the tumbler. If the soil is acid, the litmus should be red in the tumbler containing the soil but unchanged in the one containing no soil. If the litmus should turn red in the one containing no soil, then the blotting paper or the water contains some acid, or perhaps both, in which case different paper or water would be needed to make a satisfactory test.

For quick use in the field, the litmus paper can be applied directly to a ball of damp soil, but this method gives less reliable results.

An abundance of calcium carbonate in a soil is usually indicated when red litmus paper, used as directed above, at first becomes neutral in tint (neither distinctly blue nor red) and in the course of half an hour turns to a blue color. A rapid change from red to blue usually indicates "black alkali" (p. 28).

In the case of soils containing large amounts of calcium carbonate, a simple test may be made by treating some of the soil with vinegar or with dilute hydrochloric

(muriatic) acid. If much carbonate is present, bubbles of gas will be given off more or less rapidly, according to the amount of carbonate present.

(2) *The ammonia test for soil acidity.*—This has been already described on page 127 in connection with a statement regarding miscellaneous organic acid compounds in soils.

CHAPTER IX

RELATIONS OF WATER TO SOILS AND CROPS

Generally speaking, the moisture supply is a large, dominating factor in plant growth. The efficiency of fertilizers in crop growing is dependent upon the water supply furnished by soils, when other conditions are favorable. Plants utilize food material only when it is in solution in water. It is a well-known fact that the effect of an applied fertilizer may be wholly lost in a dry season, although it is also true that a well-fed crop withstands drouth better than one poorly fed. We shall consider the subject under the following divisions:

1. Functions of water in plant growth.
2. Distribution of water in soil.
3. Loss of soil water.
4. Control of soil water.

FUNCTIONS OF WATER IN PLANT GROWTH

Water performs the following functions in relation to plant growth: (1) It dissolves plant-food in the soil; (2) it acts as a carrier of dissolved plant-food from soil to plants; (3) water furnishes the hydrogen and oxygen used in large amounts by plants; (4) water keeps the cells of plants in a swollen condition, an essential for plant growth; (5) the temperature of plants is influenced by the evaporation of water from leaves.

Solvent action of soil water.—The mineral constituents of the soil are somewhat soluble even in pure water, and still more so in water which contains in solution carbon dioxide and oxygen, as in case of rain water and water in soils rich in decomposing organic matter. Different com-

pounds in soils vary greatly in regard to the ease with which they dissolve in soil water, but they are all in some degree continuously undergoing gradual solution and changing their plant-food constituents from unavailable to available forms.

Action of water as a carrier.—Water carries through the plant the gaseous food constituents taken from the air; it takes the dissolved mineral plant-food into the plant-roots (p. 163) and through the plant from one part to another; it also transfers within the plant the various soluble products formed by the plant, carrying them from one part to another for assimilation (p. 166), as development requires, much as the blood in the animal body carries to every tissue and organ the nutriment needed.

Water as a source of plant-building material.—Water is a direct plant-food; it furnishes materials which are used in large amounts in building plant tissues. It is used either directly as water or it is decomposed into its two constituents, hydrogen and oxygen, which are then used to form new compounds (cellulose, starch, sugar, oils, proteins, etc.). Hydrogen makes up 6 to 7 per cent. of the dry matter of plants, and this all comes primarily from water. Oxygen is present in the dry matter of plants in considerably larger proportions than hydrogen, and practically all of it is supplied by water. If we consider plants in their fresh state, the proportion of water contained as such in them is very large, much larger than all other constituents together. The amount of unchanged water in a fresh crop at full growth averages about 80 per cent. of the weight of the crop. The limits of water in growing plants in general may be placed between 60 and 95 per cent.

Action of water on plant-cells.—Plant-cells maintain the conditions of highest activity only when well distended or swollen; this condition is technically called *turgor* (p. 167). Absence of a sufficient supply of mois-

ture is indicated by wilting, which is caused by the shrinking of the cells, due to lack of water. The swollen condition of plant-cells gives firmness to the soft parts of plants, enabling small, soft stems to carry branches, leaves, flowers and fruit of considerable weight. The turgor of plant-cells is said to be influenced by the presence of potassium compounds.

Large amounts of water required for plant growth.— The growth of crops requires large amounts of water, (1st) because plants average about 80 per cent. of water in weight and (2d) because large amounts of water pass through the plant and evaporate from the leaves into the air (p. 168). Most of the water that enters a plant through the roots is finally evaporated as water vapor into the air from the surface of leaves; this process is known as *transpiration.* The amount of water thus transpired into the air is immensely greater than that retained in the plant. Some plants exhale their own weight of water during 24 hours in hot, dry weather. The amount of moisture transpired varies with (1) the kind of crop, according to whether it has a large or small leaf surface; (2) the character of the climate; (3) size of crop; (4) the amount of moisture supply and other conditions. For each pound of dry matter in a mature crop, the amount of water transpired during the growing season may vary from 200 to 900 pounds. The usual variations for common crops are between 300 and 500 pounds in the northern portions of the United States. Expressed in another way, the total amount of water transpired during growth by an average crop on one acre of land varies from 400 to 1,000 tons, which is equivalent to a mass of water covering the ground to a depth of 3.5 to 9 inches. Soils remaining uncropped are found to contain more moisture than when cropped, if comparison is made at any given time during the season.

DISTRIBUTION OF WATER IN SOILS

Water exists in soils in three different conditions: (1) Free, (2) capillary, and (3) hygroscopic.

Free water (known also under the names of gravitational, hydrostatic, ground and bottom water) is readily apparent to the eye and touch. It saturates the soil, filling the spaces between the soil particles. It is evident in surface soil after rain, when it can be easily recognized

By gravity water goes into the soil, by capillarity it circulates through the soil and upwards, and unless prevented by a mulch, it goes out into the air by evaporation.

by sight as water. It moves downward into the subsoil under the influence of gravity, until it reaches a fixed level, where the pore-spaces are already full of water. This level varies greatly in different locations; in some, it may be many feet; in others, within a few inches of the surface, while in some cases it is at the surface. This level of free water in soils is usually known as the *water-*

table. The upper surface of free water can be ascertained by digging a hole in the ground until water stands in it. The water-table is the level at which water stands in wells. This free water is the source of springs and ordinary wells. In swamps and standing bodies of water, the water-table is at the surface of the ground or above it.

Good drainage encourages the roots to strike downward and when drouth comes the plants do not suffer.

Free or ground water is of use to plants when it is below the layer of root growth, but near enough to the surface to be pumped up by capillary attraction to the upper layers of soil. When so near the surface as to saturate any portion of the soil penetrated by roots of crops it may be regarded as unavailable, injuriously affecting growth in case of most crops, because (1) it shuts off needed supply of air; (2) it makes the soil cold; (3) it prevents formation of nitrate nitrogen (p. 211), while favoring decomposition and loss of any nitrate present; (4) it promotes the formation of compounds poisonous to plants; (5) it retards decomposition of organic matter

and produces other conditions unfavorable to crop growth. In such cases, the water-level must be lowered by a proper system of drainage (p. 156). Some plants, however, grow naturally when their roots are under water, among which are cranberries, rice, taro (*Caladium esculentum*) and swamp vegetation.

Capillary water surrounds soil particles in the form of a thin film. This furnishes the principal source of available water supply for crops; it is the most effective form for dissolving and holding plant-food. The capillary form of water moves from moist portions of soils into those less moist. The usual tendency, therefore, under ordinary conditions is for capillary water to move from lower to upper layers of soil. The distance that capillary water can move depends upon the arrangement of the soil particles and the resulting air-space, but is usually limited to a few feet. The stirring of soils of close structure, like clays for example, usually increases the air-space, the extent to which capillary water can move, and the water-holding power of the soil. In coarse, sandy soils, where the air-space is large, stirring has an opposite effect, decreasing the extent of capillary movement and the water-holding power.

The amount of capillary water in soils depends upon (a) the size of the soil particles, (b) the structure, and (c) the amount of partly decomposed organic matter. The finer the soil particles, the larger is the amount of capillary water. Loose, open structure, as in sands, is unfavorable to water-holding power; the very close structure of clay soils may have the capacity for capillary water increased by promoting the crumb-structure (p. 101) to a certain extent. The effect of decomposed organic matter in soils upon the water-holding power has been discussed already (p. 134).

Hygroscopic water is that held mechanically by soil particles and is not moved by capillary attraction or

gravity; it is the moisture remaining on soil particles when soil is dried in air. It forms the smallest proportion of the three forms of soil water. Plants do not appear to be able to make any use of hygroscopic water.

LOSS OF SOIL WATER

Water is lost to soils (1) by percolation, (2) by evaporation, and (3) by growing plants.

Percolation.—When a soil is saturated with water, that is, when all the spaces between the soil particles are completely filled, the water tends to go down under the attraction of gravity and continues until it reaches the water-table. This downward movement of free water through the pores of the soil is known as percolation. Its amount depends upon several conditions, among which are (a) texture and structure of soil, (b) amount of rainfall, and (c) the presence or absence of growing plants on the surface. In soils of fine texture, such as clay, percolation is slower; in soils of coarse texture, like sand, the downward movement of water is more rapid. The larger the size of the spaces between the soil particles, the more rapid will percolation be. Soils covered with growing plants retain more water in the upper layer than bare soils. The amount of percolation is greater in case of heavy rainfalls than in light. Where rainfall is fairly abundant, loss of water by percolation may amount to one-half of the rainfall.

Evaporation.—A large amount of water is lost to soils by direct evaporation from the surface of the soil. The amount of water lost by evaporation is influenced by (a) temperature, (b) humidity, (c) winds, etc. A combination of dry air, high temperature and strong winds affords the most favorable conditions for surface evaporation. Loose, open soils lose water by evaporation to a greater extent than soils of close structure.

Transpiration.—The amount of water transpired by plants has been noticed (p. 147); this loss is essentially evaporation from the surface of the portion of plants above the soil, more particularly the leaves. Little can be done by soil treatment to influence this loss. When the amount of water transpired is greater than that supplied by the soil, plants wilt.

Water-holding power of soils.—Soils vary greatly in their capacity for holding water, depending upon various conditions, among which are (1) the general character of the soil and subsoil, (2) the amount of humus. Fine-textured soils or subsoils like clay take up water slowly and hold it very tenaciously, while coarse-textured soils like sand admit water freely and let go of it easily. Soils that are compact receive and hold water less satisfactorily than soils that possess a crumb-like structure.

CONTROL OF SOIL MOISTURE

In the growing of crops, one of the most important operations is so to control soil moisture that crops will be sufficiently supplied with water as they need it. This object can be accomplished within certain limits, depending upon the special conditions existing, such as the amount of rainfall, the character of the soil, and the kind of crop. Control of soil moisture is brought about by decreasing the amount of water lost, by increasing the water-holding power of soils, by removing superfluous soil water, and by direct addition of water. Among the various methods more commonly employed in accomplishing these objects are the following: (1) Tillage, (2) mulching, (3) organic matter, (4) fertilizers, (5) drainage, (6) irrigation. Our treatment of these methods must necessarily be in the nature of a summary. In the application of any of these methods, farmers must be guided by the special conditions existing in each case,

such as local conditions of soil, climate, season, crop, and general character or system of farming.

Tillage.—Under this general term are included the various operations of handling or manipulating the soil that are requisite for crop production, such as plowing, harrowing, rolling, cultivating, hoeing, etc., for the per-

CUTAWAY HARROW FOR PULVERIZING SOIL

formance of which many useful implements have been devised.

(1) *Plowing.*—Only depth and time need be considered here. In general, depth of plowing is regulated (a) by season, (b) by character of soil, (c) by length of time soil has been cropped and (d) by kind of crop. As a rule, clay soils should be plowed deeper than sandy soils. The

longer a soil has been cropped, the deeper should be the plowing. Fall plowing is usually deeper than spring plowing. Deep plowing is attended with more effective results in soils well supplied with organic matter, especially in case of light, sandy soils, which should not be plowed deep unless so supplied. One advantage of late fall plowing, especially in regions where fall and winter rainfall is not abundant, is the saving of moisture by pre-

HARROW

venting loss through evaporation and by enabling the soil to take in more water from winter rain and snow. Early spring plowing, accompanied by cultivation, is very effective in holding soil moisture. The amount of moisture in a soil, especially in heavier soils, must be considered in connection with plowing. If plowed when too moist, such soils become puddled (p. 96), and when they dry, are in a hard, lumpy state; this condition injures the water-holding power of the soil.

(2) *Harrowing and rolling.*—These operations carry further and complete the pulverizing effect of the plow; rolling, in addition, compacts the surface, retarding percolation, though increasing evaporation.

(3) *Cultivation.*—The operations included under this head affect moisture conditions, especially by furnishing the surface with an earth mulch which is simply an air-dry layer of natural soil. This loose, superficial layer of earth, sometimes called "dust-mulch" or "dust-blanket," enables the soil to absorb water more quickly and also to hold it more firmly. It is of special value in preventing excessive evaporation. When water evaporates from the surface of the soil, there is a movement of water upward from the subsoil to take the place of that evaporated, so long as soil particles lie close enough to permit capillary movement. By stirring surface soil, close contact of soil particles is disturbed in this thin layer and the water no longer passes so easily from the surface. In case of soils that crack on drying, the mulch fills these openings and prevents evaporation from them. The dry-earth mulch should be 2 or 3 inches thick. Clay mulches should usually be thicker than those of sand. Rain, if at all heavy, destroys the effectiveness of the earth mulch, which must be renewed by stirring the surface soil as soon as it is dry enough to work properly. On heavy clay soil in good tilth, even misty, foggy weather in excess may destroy the mulch to such an extent as to require renewal by shallow cultivation. Even in dry weather, a dust-mulch may become gradually compact and require fresh stirring. Generally, renewal of dust-mulches is required more frequently during spring, when rains are more common, than later. The dry-earth mulch is more easily managed on sandy soils than on clay soils. It should be kept in mind that the effectiveness of the earth-mulch depends on its fineness and dryness.

Mulching.—Any material put on the surface of the soil

to prevent evaporation is a mulch. Originally, the term applied to such materials as straw, leaves, farm manure, etc., but its present use is much wider, including these and many other materials and especially the dry-earth mulches, created by stirring the surface of the soil, as noticed in the preceding paragraph. The use of other materials than earth-mulches depends mainly upon special conditions of convenience and effectiveness. Some successful fruit-growers employ a mulch of straw or other material under the fruit-trees in place of tillage. In greenhouses, a mulch is often used by applying coarse sand or fine gravel in a layer 2 or 3 inches thick. In some special cases, crops are covered with canvas.

Organic matter.—The value of decomposing organic matter in soils as a material for holding moisture has been considered (p. 134).

Fertilizers.—Fertilizers containing soluble compounds, such as sodium nitrate, potassium chloride, common salt, etc., may exert a beneficial influence upon soil moisture in connection with crop growing, because water containing dissolved salts more readily attracts the subsoil water to the surface and tends to keep the top layer more moist. On the other hand, certain solutions like extracts of manure or organic substances containing a little oil have the opposite effect; under such conditions, soils lift less water from the subsoil, and dry at the surface more rapidly; in such cases shallow-rooted crops have the appearance of being burned, owing to lack of moisture. This is noticeable when heavy applications of fresh farm manure are followed by dry, hot weather.

Drainage has for its object the removal of free water from the layer of soil occupied by roots; the removal is effected by providing open passages through which the water may pass. Drainage is necessary in case of soils that are filled with standing water all the while, such as swamps, and also in case of soils that are saturated with

water at intermittent periods. Successful growing of crops primarily depends in large measure upon good drainage. The application of fertilizers to a soil needing drainage results in throwing away time and money. The subject can be discussed here only in a superficial way. Some special treatise on drainage must be consulted by anyone desiring full knowledge of the details of applying drainage in farm practice. The most that we can attempt to do here is to emphasize the importance of drainage by pointing out briefly some of the beneficial effects, among which are the following:

(1) *Improvement of structure of soil.*—In wet soils, there is generally lacking the desirable crumb structure, particularly in case of clay soils. Drainage promotes the formation of the granular structure, which is followed by results affecting other soil conditions favorable to plant growth, such as ventilation, warmth, etc. The soil is also made more firm by drainage.

(2) *Air supply increased.*—This results through removal of water from the pores of soils and also from increase of pore-space by granulation of soil particles.

(3) *Temperature favorably affected.*—Soils have a higher average temperature after drainage than before. Well-drained soils become warm more quickly in spring, permitting earlier seeding and they remain warm later in fall; therefore, the effect of drainage is to increase the length of the growing season. Wet soils are late and their growing season is apt to be relatively short. The increased warmth promotes both chemical changes and activity of micro-organisms in soils.

(4) *Growth of desirable micro-organisms favored.*—The growth of micro-organisms requiring air (p. 194) is favored by drainage. Among these are the organisms that promote the decomposition of organic matter and also those that produce nitrate nitrogen (p. 208). In wet soils

lacking ventilation, denitrification is apt to take place (p. 210).

(5) *Effect upon supply of food.*—Drainage promotes those biochemical changes which result in changing unavailable into available plant-food.

(6) *Removal of injurious compounds.*—Drainage, along with heavy irrigation, is found to be the most reliable method of removing from alkali soils the salts accumulated in such large amounts as to be injurious to plant growth.

(7) *Increase of available water supply.*—Drainage, while removing an excess of water, nevertheless increases the amount of water that plants can use, especially in case of fine-textured soils. Those soils that are saturated only part of the time undergo wide variations in moisture, being at one time excessively wet and at another excessively dry. When such soils are drained, crops do not suffer from deficient supply of moisture in dry spells, since their change in structure resulting from drainage enables them to retain moisture longer. Although the total amount of water in a soil is diminished by drainage, the supply available for plants is increased for the growing season, as a whole.

(8) *Effect on root growth.*—In well-drained soil, roots grow deeper; this results in their coming in contact with an increased area of soil, which enables them to obtain more mineral food and moisture and therefore to withstand drouth for a longer time.

There are other advantages that good drainage brings, but those mentioned are sufficient to show its extreme importance. Stated in practical terms, good drainage results in surer and larger crops, while it enables one to control to better advantage the times of seeding and harvesting as well as all the operations of tillage.

In the case of soils that do not grow good crops, one of the first inquiries to be made in ascertaining the cause is

in regard to the matter of drainage. On a badly drained soil, efforts to raise crops meet with poor reward, and, in the interests of profitable crops, this condition must be made right before one can expect to reap the reward of tillage, fertilizers, etc.

Irrigation consists in the direct application of water to soils. It finds its most extensive applications necessarily

SUGAR BEETS IN EXPERIMENTS WITH VARYING AMOUNTS OF WATER. UTAH STATION

where rainfall is less than 10 to 20 inches a year. However, in some special cases where crops of high value are concerned or where some special market conditions prevail, irrigation has proved profitable when the annual rainfall is 40 inches or more. From the few experiments which have been made it is doubtful if irrigation will find extensive applications outside of dry climates, except in a limited way under some special conditions. The general subject of irrigation is one which cannot be treated satisfactorily in a brief way and the reader who is inter-

ested in the subject is referred to special works treating it exhaustively.

The relation of soil moisture to special crops.—The practical importance of soil moisture is shown especially in the control which it exerts in determining locally what crops can best be grown on a soil. Generally speaking, the amount of moisture in a soil often affects the time of

SATURATION EXPERIMENTS WITH WHEAT. UTAH STATION

ripening, the yield, and in some cases, the quality of a crop. For example, early market-garden crops are best grown on light soils holding comparatively small amounts of water; while later crops of the same products are grown on loams with two or three times the water-holding capacity. In such cases, earliness is at the expense of yield, the later crops producing more heavily. In respect to influence on quality, it is well known that potatoes grown on lighter soils are, in general, superior in cooking quality to those grown on heavier soils.

CHAPTER X

HOW PLANTS TAKE AND USE THEIR FOOD

In order to understand more clearly the direct relation to plant growth of plant-food materials, both those supplied naturally and those supplied artificially, it is desirable to know something of the way in which plants take and make use of these materials.

We have already seen (p. 16) that plants obtain their food from two sources, air and soil. Two sets of plant organs, leaves and roots, are made use of in taking food from these different sources. Briefly stated, plant-food constituents taken from air and soil are conveyed through the plant to the cells, where they are separated and recombined into new forms adapted to the use of the plant. Certain natural forces are at work which enable a plant not only to absorb the air and the soil solution but to select from the constituents contained in these the particular chemical elements needed for plant use and in the proportions needed. We will now study in more detail how the plant obtains and uses its food supplies, considering the subject under the following divisions: (1) Plant-cells as manufactories, (2) how plants obtain and use carbon, (3) relation of roots to food supply, (4) absorption of soil solution, (5) turgor of plant-cells, (6) selective power of plants, (7) forms of food constituents used, (8) feeding-power of crops.

Plant-cells as manufactories.—The ability of a living plant to make use of food materials and to develop through various stages of growth from seed to maturity depends upon the work performed in the millions of the small individual cells of which plants are made up. We may regard an ordinary living plant as a chemical labora-

tory or factory, containing immense numbers of small rooms, which we call plant-cells, each of which contains everything essential for its work of production, and in which there is at one time or another intense industrial activity. While plant-cells vary in size, shape and other details, it will answer our purpose to describe certain general properties of fundamental importance belonging to living cells in common. We can think of a plant-cell as a very small, bladder-like sac, consisting essentially of two parts, the covering and the cell contents. The important thing to know in this connection about the cell-covering or wall is that, in the young, growing portions of plants, it is a thin, firm, strong and elastic membrane, through which water, gases and dilute solutions, but no solid particles, however small, can pass. Each active plant-cell is filled with a semi-liquid substance, known as *protoplasm,* which is a very complex mixture of many different compounds, such as water, nitrogen, carbohydrate and other organic compounds, together with mineral compounds in solution. Protoplasm is the living part of plant-cells; it is this which makes life processes possible. It is this substance in which and through which chemical changes take place in cells, resulting in the processes of assimilation, the breaking down of one set of compounds to form new ones. In the presence of, and from the substance of, protoplasmic material are formed all the different compounds found in plants, such, for example, as sugar, starch, cellulose, proteins, oils, acids, poisons, flavoring compounds, etc.

In what manner the cells obtain the food materials from air and soil to make use of in their work of constructing new compounds we shall now endeavor to make clear.

How plants obtain and use carbon.—As previously stated (p. 85), nearly one-half of the dry matter of plants consists of carbon, and this all comes from the car-

bon dioxide present in the air. The air is inhaled by the plant through special small openings or breathing-pores distributed thickly over the under surface of leaves. The air with its carbon dioxide passes into these openings and then through the plant into the spaces surrounding the plant-cells, which absorb the gas as it is needed; inside the plant-cell the carbon is separated from the oxygen and made to combine with other elements to form new compounds, while the separated oxygen passes back for the most part into the air. The ability of the cell-protoplasm to utilize the carbon of carbon dioxide depends mainly upon two factors, *chlorophyl* and *sunlight*. Chlorophyl is the name of the green coloring-matter in plants characteristic of leaves. It is contained most abundantly in the cells of leaves mixed as small green particles with the protoplasm. This green substance has the power to absorb sunlight, and through the energy thus obtained and with the aid of protoplasm, the carbon dioxide is decomposed into its constituent elements, oxygen and carbon; the free carbon then unites with other elements to form new compounds, which appear in the cell first as a carbohydrate, probably starch. This process of using carbon to form new compounds is known as *assimilation* or *fixation of carbon*. This action does not take place in the absence of sunlight, as shown by the white color of plants grown in the dark. The rapidity of fixation of carbon depends upon the intensity of sunlight, temperature, supply of water, the amount of carbon dioxide in the air, the number of breathing-pores in the leaves and the supply of other kinds of plant-food (nitrogen, phosphorus, potassium, etc.). As previously stated (p. 81), the presence of a small amount of some soluble iron compound is necessary for the formation of chlorophyl.

Relation of roots to food supply.—The plant-food constituents contained in the soil (water, nitrate nitrogen,

compounds of potassium, phosphorus, calcium, iron, magnesium, etc.) enter plants through the roots. Plants can use these constituents only in the form of solution because solid particles, however small, are unable to pass through the thin walls of plant-cells. The soil water dissolves some of the plant-food material with which it comes in contact and this nutrient solution passes into the roots, not through all portions of the root surfaces, but through the *root-hairs*, which deserve special notice. If a growing plant is carefully removed from the soil so as to disturb its roots as little as possible, slender, white, hair-like branches are found very near the tips of the smallest rootlets that branch out from the larger roots and penetrate the soil in all directions. These root-hairs are so numerous that over thirty thousand may in some cases be found on one square inch of root surface. They are often so numerous and fine as to have a fuzz-like appearance. It has been estimated that the area of root surface is commonly increased five to twelve, and in extreme cases over fifty, times by the growth of root-hairs. In a soil well supplied with water and other available plant-food, the number of root-hairs is very much larger than in the case of soils lacking in moisture and other nutrients. The feeding-power of a plant is therefore, greater in rich, well-watered soils than in dry, poor soils.

Cross-section of root magnified. *p*, layers of soft, thin-walled cells; *e*, cells forming outer covering of root or epidermis layer; *h h*, root-hairs.

Each root-hair is a long, single-celled tube, the walls of which are so exceedingly thin and delicate as to allow water or solutions to pass through, but not solid particles.

The tip of each rootlet is constantly pushing through the soil in search of food, and new hairs are continually being formed just back of the growing tip, the old ones ceasing their activity and disappearing as the result of death and decay.

Another fact of interest and importance is the intimate way in which these little hairs get around among the fine soil particles. They not only grow between the soil particles but actually apply themselves most closely to them, frequently almost inclosing the particle. In this way the cell-wall of the root-hair is brought into closest possible contact with the thin film

ROOT-HAIRS

HOW PLANT-FOOD GETS INTO THE SOIL

Carbon is taken in through the stomata, or mouths, on the underside of the leaf. All the mineral elements, including the nitrates, are in solution in the water and pass in this way into the plant through the root-hairs near the tip end of the growing root. Later most of this same water passes out of the leaves as vapor.

of water surrounding the soil particles, absorbing the moisture and also any compounds it carries in solution.

It has long been a disputed question as to what extent and in what manner the acid solution in the root-hairs helps to dissolve some portion of the soil particles directly; there is good reason to believe that the sap within the root-hairs has some such direct dissolving action on soil particles. The weight of evidence at present appears to indicate that the chief dissolving agent excreted by root-hairs is carbon dioxide, though it is easily conceivable that the acid salts and free organic acids in plant juices may be passed out through the cell-wall around the soil particles and take part in the dissolving action.

The nutrient soil solution, after being taken into the root-hairs, is passed on into the roots and carried through other sets of cells up into the leaves, where its constituents are utilized in various manufacturing operations. The process by which the soil solution passes into the root-hairs and is transferred from the roots to the manufacturing parts of the plant is one of practical interest, and to this we will now give attention.

Absorption of soil solution.—The movement of gases, of pure water, or of water containing dissolved substances, through a membrane, is known by the special name of *osmosis*. It applies to the process by which soil water passes into root-hairs; it applies also to the movement of gases and solutions within the plant into and out of the various cells. There is one main condition which determines whether water, or a compound dissolved in water, will pass through the covering membrane into a cell or out of it, and that is the relative concentration of the solution in the cell and the solution outside. Under ordinary conditions, the solution or cell-sap in the root-hairs is more concentrated than the soil solution: that is, it contains a smaller proportion of water to

the substances dissolved in it; water then passes from the soil into the root-hairs. The solution passes. by the same process of osmosis, from root-hairs into other cells in the roots and from these into still other sets of cells, until finally it reaches the leaves which are all the while using for their manufacturing operations those materials in the cell-sap that are needed for making plant tissues and other products. The water not used or needed is passed from the leaves into the air by transpiration (p. 152). This evaporation of water from leaves makes the cell-sap more concentrated in the upper portion of the plant; the movement of water will therefore be upward to replace the water lost. If at any time the soil solution is more concentrated than the cell-sap, then water passes from the root-hairs into the surrounding soil water.

In this connection, it is a fact of practical importance to know that when the solid matter in a soil solution is greater than 1 part in 500 parts of water (for example, 1 pound in 60 gallons of water), the solution is approaching a concentration beyond which it may cause many plants to suffer. This is shown when leaves turn yellow on the edges, become spotted and drop off, or growth is checked, shortened and dwarfed, and leaves often become puckered and twisted. The roots and root-hairs are also shortened and deformed.

Turgor of plant-cells.—We have already referred to the swollen condition of plant-cells, known as *turgor*, which enables the cells and organs of plants to maintain their shape and keep in condition for performing their work. The turgor of plant-cells is intimately connected with the process of osmosis. The passage of water by osmosis into cells causes them to fill up to such a degree as to produce pressure from within on the cell-wall and to cause a more or less rigid, swollen condition. This condition is maintained by continued absorption of water, which takes place so long as the cell-sap is more concen-

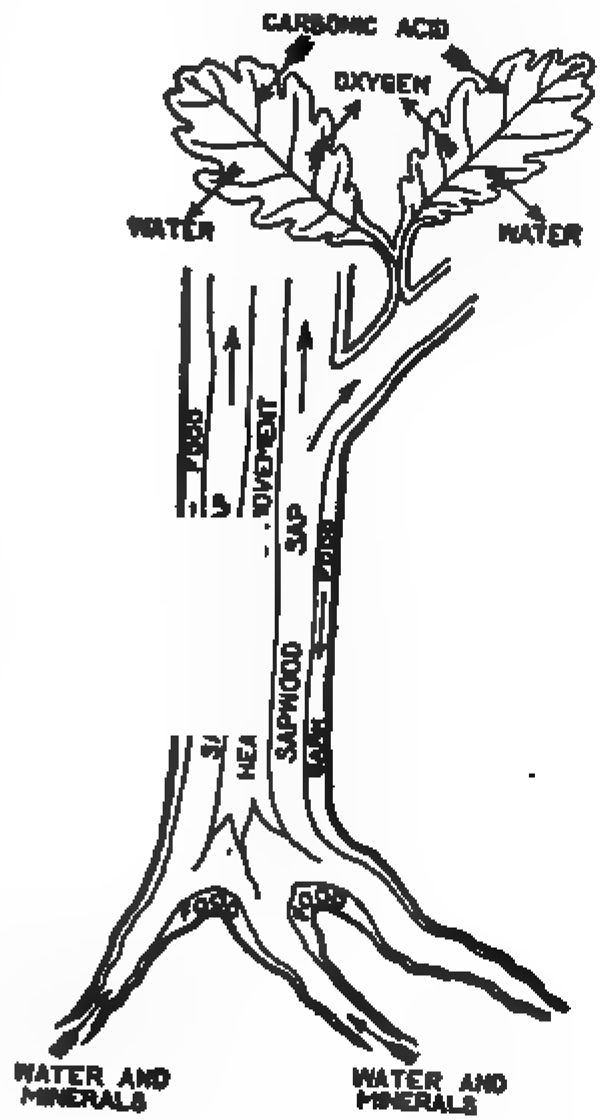
trated than the solution outside the cells. When, on the other hand, soil water is more concentrated than cell-sap water leaves the plant-cells, passing into the soil, the plant-cells lose their fullness, the tissues wilt or become limp, if the withdrawal of water is carried too far, and the plant may die. We have practical illustrations of loss of turgor in plant-cells when a strong solution of nitrate of soda, for example, comes in contact with a green leaf; water passes by osmosis from the cells to the stronger solution outside to such an extent as to cause the leaf to wilt and present a scorched or burned appearance. A similar result takes place when a concentrated fertilizer, rich in salts such as sodium nitrate, ammonium sulphate, potassium chloride, sulphate, etc., is applied in too large amounts to a soil; under these conditions, more water leaves the plant than enters and the plant wilts.

Root-hairs on wheat when very young and four weeks later. All the water and food from the soil enter the plant through the root-hairs. Note how closely the root-hairs adhere to the soil particles. (After Sachs)

In hot, dry weather, when there is insufficient water in the soil to supply the place of that evaporated from the leaves, plant-cells lose their turgor and the leaves show more or less appearance of wilting; in such cases, the wilting acts as a protection in preventing more water from going off too rapidly, since the openings in the leaves, or breathing-pores, through which the water

passes into the air, become much smaller through loss of turgor in the cells around the openings.

Selective power of plants.—It is well known that plants use some soil constituents in much larger amounts than others, and it is a matter of practical interest to consider briefly how a plant obtains its food supplies in the proportions needed. The soil solution contains various constituents, some of which nourish plants and some of which do not. Through the process of osmosis, plants exercise a certain kind of power of selection, distinguishing between nutritive and non-nutritive constituents, and between those used in smaller and those used in larger amounts. The amount of each constituent present in the soil solution that is taken into a plant is determined primarily by the amount of each constituent used by the plant in its manufacturing work; the process of osmosis automatically acts to keep up the supply. When a plant-food constituent is taken from its solution within the plant-cell and built by the protoplasm into some new form, then a new supply of that particular constituent



HOW THE SAP CURRENT MOVES

passes into the cell from the solution outside as soon as the amount of that constituent in the solution within the cell becomes less than in the solution outside of the cell. For example, taking a single food element like potassium, whatever amount is present in the cell-sap is sooner or later taken from the solution by the protoplasm in the cell for use in the work of plant building, leaving the solution within the cell containing less potassium than the solution outside; then there will be a fresh inflow of potassium until the proportion of potassium is the same in the solution within and without the cell. Should the potassium be used as fast as it is absorbed, then absorption continues rapidly enough to maintain the supply. In the case of a constituent like sodium, of which plants use only small amounts at most, new supplies are not called for within the manufacturing cell to any appreciable extent, and therefore the cell-sap holds all it can and no more is admitted to the plant from the soil. In the case of potassium and sodium, the soil solution usually contains more sodium than potassium salts, but in spite of this we find more potassium in the plant. Therefore, the amounts of different plant-food constituents that come into roots through the root-hairs are regulated not merely by the amounts present in the soil solution but more largely by the amount of each constituent removed from solution within the plant-cells for use in manufacturing operations. This power of taking from soil solution any plant-food constituent or constituents needed is known as the *selective power* of the plant. This selective power exists within the living cells themselves. All materials dissolved in soil water pass by osmosis through the walls of the root-hairs into the plant, but they will not continue to enter unless they are made use of by the protoplasm and removed from solution.

Forms of constituents used.—We ordinarily think of compounds in soil solutions being absorbed by plants in

the exact form in which they exist in the soil solution. For example, we usually suppose that the sodium nitrate in a soil solution passes as such into the plant, but it does not necessarily. When a plant is grown in a water solution and sodium nitrate ($NaNO_3$) is supplied, the compound is split into sodium (Na) and nitrate radical (NO_3); the nitrate is used by the protoplasm, while the sodium is rejected, which, combining with any carbon dioxide

ROOTS OF SOFT MAPLE AS THEY GREW IN THE SOIL OF A TILLED FIELD. KANSAS STATION

present, appears as sodium carbonate in the solution outside the plant. As a result, the surrounding solution soon becomes alkaline. In other cases, as with potassium chloride (KCl) or sulphate (K_2SO_4), the plant uses the potassium and rejects for the most part the acid portion (Cl or SO_4), the presence of which results in making the surrounding solution acid. We are to regard each

individual element or radical in the soil solution as being taken up and used independently by plants; the supply of each by itself comes in accordance with the demand made on each for manufacturing operations. Each element or base or acid is used and supplied more or less independently of the others.

Feeding-power of crops.—We are in the habit of speaking of some crops as "weak-feeding" and others as "strong-feeding." In these expressions we recognize the fact that some crops obtain abundant supplies of plant-food from soils on which other crops suffer for lack of food. For example, corn, oats and cabbage often grow well on soils where onion or wheat crops give poor yields. Stated in the briefest way, the feeding-power of a crop depends on its ability to absorb plant-food from the soil; and this depends upon several factors, chief among which are the extent or area of the root-hairs and the activity of the plant's chemical processes. Plants which have large root systems and a proportionately large number of root-hairs are in condition to absorb more plant-food than plants which have small root systems. The rapidity with which plants use their food in making new growth and in elaborating various compounds affects their feeding power. The larger the amount of constituents used in the plant, the larger must be the amount absorbed. A crop in its most rapid stage of growth absorbs more plant-food material than at other times. The chemical action of root-hairs in dissolving soil particles also influences the amount of plant-food absorbed. This action may account for differences observed in the case of different plants in relation to the greater readiness with which they use certain forms of plant-food.

Effects of plant-food distribution on root growth.—Roots in growing are attracted in the direction of the most available food supply. Experiments made in a poor soil in such a way that soluble plant-food is placed in

certain locations in a vessel holding the soil show that the root development varies according to the location of the plant-food. For example, when the plant-food is uniformly mixed through the soil, the roots grow evenly throughout the entire soil mass. When the food material is placed about one inch below the surface, the roots form a mat in this layer and those that extend beyond are not

Root-hair in soil magnified, showing absorption of soil solution; *h*, is a root-hair forcing its way between soil particles (*s*) which are the dark portions; the large, rounded, white spaces (*a a*) represent air bubbles; the waved lines (*w*) surrounding the particles of soil and inclosing air bubbles represent water held to the grains by surface attraction. At points marked *c*, near the end of the root-hair, the soil particles are in close contact with the root-hair.

much branched. When the plant-food is placed about the middle, between top and bottom, the root system shows great expansion at this point. When the fertilizer is placed at the bottom, the roots are slender and, without branching much above, form a mat at the bottom. When the plant-food is placed in a layer around the cylinder

of earth next the sides of the vessel holding the soil, the outside roots are greatly branched, but the inner ones are only slightly developed. When the food material is so placed as to form a core down the middle of the cylinder of soil, the inner roots are greatly developed, while the outer ones are less so. The root growth takes place where the food supply is.

CHAPTER XI

LOSSES AND GAINS OF PLANT-FOODS IN SOILS

Some knowledge of the ways in which the amounts of plant-foods in soils are decreased and increased, and some appreciation of the extent to which different forms of plant-food are liable to loss, are essential to an intelligent and economical use of fertilizers in the growing of crops. We therefore devote a few pages to a brief study of the more important facts relating to the losses and gains of plant-foods in soils.

LOSSES OF PLANT-FOODS

The fact that plant-foods are removed from soils has been long established, but the precise ways in which, and the extent to which, such losses take place have not been clearly understood nor fully appreciated until recent years. Plant-food constituents are lost from soils in the following ways: (1) By growth and removal of crops, (2) by the process of leaching, (3) by mechanical agencies, (4) by conversion into gaseous form and escape into air.

Removal of plant-foods by crops.—The far largest amounts of plant-food constituents are removed by crops grown on and taken away from the land. Different crops use the same plant-food constituents in very variable amounts, and this fact must be taken into consideration in determining what crops to grow to advantage when the crops are to be sold. The amount of plant-food consumed is an essential factor in estimating the cost of growing a crop for market. This is not, however, a matter of so much importance where a crop is utilized on the

farm in feeding animals and a large proportion of its plant-food constituents returned to the soil.

The following table serves by way of illustration to give an approximate idea of the amounts of the more important plant-food constituents used by a few typical crops. Data regarding other crops will be given in Part Four at the end of each chapter in connection with our study of the practical fertilizer needs of various crops. The figures given in this and other chapters are based upon the best data available, but it must be kept in mind that they are only approximations to what may be regarded as fair conditions of yield and cannot be applied too closely to any individual case. It has seemed preferable to base our data upon moderate rather than upon maximum or minimum conditions. From the data given, one can easily estimate the amounts of plant-food constituents removed by a given crop when the yield is known. For example, we have based our estimate of the plant-foods removed from a soil by a wheat crop on a yield of 25 bushels of grain an acre. If the yield in a particular case is 12½ bushels, the amount of plant-foods removed will be one-half that given in the table; if the yield in another particular case is 50 bushels, the plant-food used by the crop will be twice that given in the table.

In those cases where unused portions of a crop go back directly to the soil, as with the leaves of fruit-trees, small fruits, the leaves and stems of many vegetables, etc., we have given results in most cases only for the portion of the crop actually removed from the soil, although in some cases we have included also information for the portions of the crop not removed from the field.

When a crop is sold as taken from the field, the amount and composition of the crop are a direct measure of the loss of plant-food to the soil. When a crop is fed to animals on the farm and the manure put back on the soil on which the crop was grown, then only a small part of the

plant-food constituents is actually lost to the farm (p. 298).

TABLE 21—PLANT-FOOD CONSTITUENTS IN A CROP GROWN ON ONE ACRE

Kind of crop	Portion of crop	Yield	Nitrogen lbs	Phosphoric acid (P_2O_5) lbs.	Potash (K_2O) lbs.
CORN	Grain Stalks, etc. Cobs	25 bu 1500 lbs 250 "	23.2 15.0 1.0	9.1 (4. P) 4.5 (2. P) 0.2 (0.1P)	5.5 (4.6K) 21.0 (17.4K) 1.1 (0.9K)
			39.2	13.8 (6.1P)	27.6 (22.9K)
WHEAT	Grain Straw	25 bu 2500 lbs	30.0 12.5	12.8 (5.6P) 3.8 (1.7P)	6.0 (5. K) 15.0 (12.5K)
			42.5	16.6 (7.3P)	21.0 (17.5K)
OATS.........	Grain Straw	25 bu 1250 lbs	16.0 8.0	6.5 (2.9P) 2.5 (1.1P)	4.8 (4K) 15.6 (13K)
			24.0	9.0 (4.0P)	20.4 (17K)
APPLES ...... (30 trees per acre)	Fruit Leaves New wood	300 bu 1000 lbs 100 "	6.0 10.0 0.5	3.0 (1.3P) 1.5 (0.7P) 0.2 (0.1P)	15.0 (12.5K) 3.5 (2.9K) 0.3 (0.2K)
			16.5	4.7 (2.1P)	18.8 (15.6K)
CABBAGE.....		10 tons	*60.0	20.0 (8.8P)	80.0 (66.4K)
BEANS	Seeds Straw	25 bu 2000 lbs	60.0 28.0	18.0 (8. P) 6.0 (2.6P)	19.5 (16.2K) 38.0 (31.5K)
			88.0	24.0 (10.6P)	57.5 (47.7K)
PEACHES..... (100 trees per acre) (	Fruit Leaves New wood	400 bu 5300 lbs 1500 "	22.2 47.7 8.6	11.0 (4.8P) 8.0 (3.5P) 2.0 (0.9P)	45.5 (37.7K) 42.0 (35. K) 2.5 (2. K)
			78.5	21.0 (9.2P)	90.0 (74.7K)
TURNIPS	Roots	10 tons	50.0	20.0 (8.8P)	90.0 (74.7K)

Phosphorus, P. Potassium, K.

Loss of plant-food by leaching.—Plant-food constituents in soils dissolve in soil water to a greater or less extent, and, when rainfall is in excess of what the soil can hold, the portions dissolved in water pass away in the drainage. While a small amount of dissolved material is carried away in the surface drainage in the case of sloping or hilly land, most of the water falling on cultivated land is carried first into the subsoil with its dissolved material

en, to a greater or less extent, passes from the soil nently in the form of drainage water. The dis- soil constituents in drainage water sooner or later eir way to the sea. It has been estimated that 5,000,000,000 tons of mineral matter *in solution* are ly transported by the rivers of the earth from the the sea. While all soil constituents are in some soluble in soil water and therefore liable to removal soils, some are much more so than others; and those most readily soluble are some of the most ant plant-food constituents. The liability of differ- nt-food constituents to loss in drainage water we nsider later (p. 185).

es by leaching depend upon several conditions, mportant of which are the following: (1) The t and time of rainfall, (2) the absorbing and hold- wer of the particles in soil and subsoil, (3) the t of organic matter in the soil, and (4) the form or unds in which the plant-food constituent is present.

Loss by leaching in relation to amount and time of l.—Large amounts of rainfall increase the amount ble plant-food removed in drainage water. Rain- ring the summer season, when the amounts of solu- nt-foods in soils are largest, causes greater loss by g than at other times of year, other conditions he same.

Loss by leaching in relation to the absorbing and power of soil particles.—The tenacity with which bsorb and hold moisture (p. 181) is influential in lling the amount of plant-food material lost in ge. On this account, clay soils lose plant-food less than sandy soils. In addition there is, in case of of the plant-food compounds, a certain amount of al action in many soils, especially clay, which tends ease or prevent leaching, a subject which we will er in more detail a little later.

(3) *Loss by leaching in relation to organic matter in soils.* We have previously (p. 134) pointed out that one of the important properties of decaying organic matter in soils is its absorbing and holding power for water and the materials dissolved in it. Keeping in the soil generous amounts of organic matter is one of the most effective means of decreasing the amount of plant-food materials lost in drainage water. The lighter the soil, the greater is the need and the more pronounced the effect.

(4) *Loss by leaching in relation to form of plant-food constituents in soil.*—It is well established that some compounds are not easily held by any soil constituent while others are. All nitrate compounds are easily soluble in water and do not form insoluble compounds with any of the soil constituents; therefore, of all forms of nitrogen compounds, nitrates are most easily lost in drainage water. We will consider other compounds of nitrogen, together with compounds of potassium and phosphorus, in this relation, under another head (p. 185).

Remedies for loss of plant-food by leaching.—In addition to keeping soils supplied with an abundance of humus and making the surface of cultivated soils open to the reception of rainfall, the most effective method of diminishing the losses of plant-foods due to leaching is to keep the ground occupied with growing plants as much as possible. The roots are able to use the plant-food during the growing season about as quickly as it becomes soluble. During the portions of seasons when the ground would otherwise lie bare for any considerable period of time, cover-crops should be grown as far as practicable In this way the soluble plant-food is taken up by the cover-crop and thus its loss by leaching largely prevented.

Loss of plant-food by mechanical agencies.—Soil particles are carried bodily from soils into streams, especially in bare, hilly regions, and the amount of plant-food material

thus removed is very large in the aggregate. The portion thus removed by water running over the surface consists of the finest soil particles, and these contain the largest part of the quickly available plant-food of the soil. The removal of these finer particles also affects most seriously the physical condition of the soil. Loss of soil particles by flowing water is promoted when land lies bare and uncultivated, unprotected by any covering of trees or other vegetable growth. Losses occurring in this manner may be largely reduced or prevented by one or more courses of treatment, according to special conditions: (a) By keeping well stirred the surface of the soil under cultivation, so that rains sink in instead of running off from the surface; (b) by keeping the soil occupied with crops as much as possible during the time when rains are most abundant; (c) by keeping the soil well supplied with organic matter; (d) by proper underdrainage; (e) in case of hilly land, the soil is handled so as to make furrows or ridges or terraces, according to special conditions, around the hill in such a way as to catch and hold the rain-water. Steep hills should be covered with trees or fine-rooted crops, like some of the grasses, as a protection against mechanical loss.

In addition to loss through the agency of running water, soil particles on the surface are also lost through transportation by winds. In some regions, this loss is one of serious proportions. This may be remedied (a) by covering the surface with growing plants, (b) by maintaining a good supply of organic matter, (c) by windbreaks, and (d) by any form of mulch.

(4) *Loss of plant-food by conversion into gases.*—The only form of plant-food that is liable to appreciable loss as gas is nitrogen. When nitrate nitrogen is decomposed into free nitrogen (p. 210), the plant-food value is lost. It is possible also that ammonia nitrogen may be lost to soils by passing into the air when the soil is hot and dry

and lacking in humus. Ordinarily, the amount of nitrogen lost either from decomposition of nitrate or from escape of ammonia into the air may be regarded as insignificant under agricultural conditions commonly prevailing. Another source of nitrogen loss is the burning of animal or vegetable matter. When stubble is burned over, or any other form of vegetable material, or any animal substance, the nitrogen is rendered useless as plant-food by being converted into free nitrogen.

How plant-food compounds are held by soils.—If a plant-food compound, such as potassium chloride, calcium acid phosphate, ammonium sulphate, etc., is dissolved in water and this solution poured upon a 6-inch layer of ordinary soil in such a way as to enable one to catch the solution draining through the soil, it will be found that most of the plant-food constituents are retained in the soil. This retention is due in part to chemical and, in part, to physical causes, and varies with the compounds applied and with the compounds in the soil, as well as with the fineness of the soil particles. We will now consider briefly these two processes by which soils are able to hold plant-food compounds applied in soluble forms. It is obvious that these processes are of much practical interest in connection with a study of the loss of plant-foods by leaching. The process by which a soluble compound is held in a soil so firmly as not to be appreciably leached out is known as *fixation*, which, as already stated, may be due to chemical or physical causes or both.

(1) *Chemical fixation* applies to those cases in which a soluble compound, applied to the soil, undergoes chemical reaction with one or more constituents of the soil and is thereby changed into another compound or compounds less soluble. We will consider this form of change in relation to compounds of nitrogen, phosphorus, potassium and calcium.

(a) Nitrogen compounds. *Nitrate nitrogen* is not chemically held in soils for the reason that all nitrates are easily soluble in water, and, therefore, cannot form insoluble compounds by reaction with any soil constituent.

Ammonia nitrogen, whether as gaseous ammonia, ammonium carbonate or a neutral ammonium salt like ammonium sulphate, is capable of reacting with certain constituents of the soil and entering into combinations which are not easily leached from the soil; and the same is true of soluble organic nitrogen compounds. It has been learned that the fixation of ammonia and of soluble organic nitrogen compounds is dependent on the presence of calcium carbonate, clay and humus in soils. While compounds of ammonia and of organic nitrogen are retained in soils so long as they maintain their insoluble condition, they are sooner or later changed into nitrate nitrogen (p. 204) and then they are easily removed by leaching.

(b) Phosphorus compounds. The amount of phosphorus compounds found in drainage water is very small. This is easily explained by the fact that phosphoric acid is capable of forming insoluble compounds with several constituents common in soils, such as calcium carbonate and also the compounds of iron and aluminum that are present in large amounts in clay. When we put soluble calcium phosphate ($CaH_4(PO_4)_2$, p. 45) on a soil containing calcium carbonate, it first goes into solution and is distributed through the soil water near the surface; soon the calcium of the carbonate combines with the soluble calcium phosphate and forms throughout the soil fine particles of the di-calcium phosphate ($Ca_2H_2(PO_4)_2$, p. 45), known also as "reverted" phosphate; or, on soils containing large amounts of calcium carbonate, more calcium may unite with the phosphate, forming tri-calcium phosphate ($Ca_3(PO_4)_2$, p. 45). Whether the di- or tri-calcium phosphate is formed, the phosphate is soon dis-

tributed throughout the upper layer of soil in a state of fine division, forming a coating on the soil particles with which the soluble phosphate comes in contact before being changed to the insoluble form. In this condition it is soluble in water containing in solution carbon dioxide or weak organic acids, and, under normal soil conditions, it goes into solution gradually to meet the demands of growing plants.

Bushels per acre, 33. Bushels per acre, 18. Bushels per acre, 38.

Experiment showing lasting effect of phosphorus compounds on clay soils. Fertilizer applied three years before. INDIANA STATION.

In acid soils and those containing only small amounts of calcium carbonate, the application of a soluble phosphate is followed by the formation of iron and aluminum phosphates (p. 49), which are only very slightly and slowly soluble in soil solutions. The foregoing facts suggest the desirability of keeping soils well supplied with calcium carbonate in order to prevent the formation of the too slowly available iron and aluminum phosphates. Some recent investigations have, however, shown marked

losses of phosphorus in case of light, open-textured soils which have been treated with large amounts of farm manure for such crops as cabbage, asparagus, tobacco, etc.

(c) Potassium compounds. Most soils contain constituents which have the power by means of chemical action to change soluble potassium compounds into forms that do not dissolve too easily in soil water. Soils containing abundance of clay and humus produce this change in greater degree than do light soils. When soluble potassium compounds, such as the chloride, sulphate and carbonate, are applied to soils, they remain largely in the the surface soil, though some passes into the subsoil, but very little goes into the drainage. In this condition the potassium remains until dissolved gradually in the soil water to supply the roots of growing plants.

(2) *Physical fixation.*—When finely powdered charcoal is shaken up in a colored liquid, the dissolved coloring-matter may be completely removed so that the solution becomes colorless. The particles of charcoal have the power of attracting and condensing upon their surfaces the dissolved coloring-matter. This is not a chemical action but is purely physical, because none of the substances taking part in the action undergoes any change in composition. This process by which a substance in solution is withdrawn from solution and concentrated and held upon the surface of small particles in contact with the solution is technically known as *adsorption*. Fine powders in general, including soil particles, have the power of withdrawing from solution and holding dissolved substances, the degree of power varying with the substance dissolved and the adsorbing solid. This process of physical fixation of soluble plant-food constituents is of importance in soils, since in fine-grained soils considerable dissolved material is held, which would be leached out. Plant-food compounds held in this way are

in condition to permit of their ready use by the root-hairs that come into contact with the soil particles. While physical fixation by adsorption may play a more or less active part in holding any dissolved soil constituent, it is of especial interest in connection with nitrates, which as we have seen, are not held in soils at all by chemical fixation, but are held to some extent by adsorption. This is shown by the fact that when we add to a clay soil a given quantity of a nitrate salt, such as sodium nitrate, and then treat the soil with successive portions of distilled water, we are able to leach out only a small part of the nitrate applied. It may be added that the finer the soil particles the greater is the adsorbing power; for this reason clay soils possess this power to a greater extent than sandy soils.

Kinds and amounts of plant-foods removed from soils. In the case of loss by mechanical agencies, such as erosion by water and transportation by wind, the soil particles, with all the kinds of plant-food contained in them, are carried away bodily; there is no selective action which removes one constituent more than another. But in case of loss by leaching, there is some selective action, which is dependent upon the solubility of the plant-food compounds in soil water. While all soil constituents are in some degree soluble in soil water and, therefore, liable to be removed from soils by leaching, some are much more so than others. The soil compounds most soluble are the chlorides, nitrates and sulphates of sodium, magnesium and calcium, and also calcium as bicarbonate.

(1) *Calcium compounds.*—Of all soil constituents, calcium is usually found in drainage water in largest amounts. In case of cultivated soils well supplied with calcium carbonate, the annual loss of this compound in drainage water is often over 500 pounds (equivalent to 280 pounds of calcium oxide) and may exceed 1,000 pounds (equivalent to 560 pounds of calcium oxide).

These large losses are due, in part, to the solubility of calcium carbonate in soil water containing in solution carbon dioxide and, in part, to the important chemical reactions in the soil in which calcium carbonate takes part. Thus, when any acid material is formed in or applied to soils, calcium carbonate is usually the first compound to be acted upon, with the resulting formation of calcium salts that dissolve easily in water. The formation of organic acids in the decay of vegetable matter and the production of nitric acid by nitrification (p. 204) convert calcium carbonate into soluble forms. The application of materials containing ammonium or potassium sulphate, chloride, nitrate, etc., results in the decomposition of insoluble calcium compounds with the formation of the corresponding salt of calcium, all of which are readily soluble in water.

(2) *Nitrogen compounds.*—As previously stated, little nitrogen is lost from soils except in the form of nitrate. There may be lost annually in drainage water under different conditions from 25 to 50 pounds of nitrate nitrogen. Organic and ammonia nitrogen are seldom found in drainage water in significant amounts, but they are sooner or later converted into nitrate nitrogen, which then may be lost.

(3) *Phosphorus compounds.*—For reasons already considered (p. 182), relatively small amounts of phosphorus compounds are lost in drainage water, only a few pounds an acre at most. If considered with reference to large areas, however, the aggregates are large, amounting for the area of the United States to 400,000 tons annually. According to some estimates, attention has recently been called to the fact that large losses of phosphorus may occur in the case of soils that have been treated continuously for long periods with large amounts of farm manure. Whether the losses occur in drainage water or in being carried into subsoil or otherwise has not been determined.

(4) *Potassium compounds.*—The amount of potassium compounds in drainage water may exceed 10 pounds an acre annually, but is usually less. The loss is increased when large amounts of soluble potassium compounds are applied, and especially on sandy soils. As compared with phosphorus compounds, the loss of potassium compounds is considerably greater under ordinary conditions. The amount of potassium annually lost to the soils of the United States in drainage water has been estimated at 3,500,000 tons.

It may be added in this connection that the loss of plant-food constituents is probably much greater in the form of solid particles carried away as the result of erosion by running water than in solution in drainage water.

GAINS OF PLANT-FOODS BY SOILS

To make up the losses of plant-food which soils suffer as a result of the different causes we have considered, there are various sources of supply that are utilized, chief of which are the following: (1) Application of fertilizers, (2) plant-food contained in rain-water, (3) nitrogen added by means of micro-organisms, (4) plant-food brought from subsoil, (5) plant-food added through manure from purchased feeding-stuffs.

Application of fertilizers.—The application of substances containing any form of plant-food material, whether a product of the farm or a commercial product, serves to furnish plant-food to take the place of that removed. The amount of plant-food thus supplied depends, of course, upon the composition and amount of the material added, details which will be considered later.

Plant-food in rain-water.—Dew and rain bring to the soil annually, from 3 to 10 pounds of nitrogen an acre, usually 4 or 5 pounds, chiefly in the form of ammonia and nitrate nitrogen. The variations in the amount of nitro-

gen thus supplied must necessarily be wide, according to rainfall, proximity of large towns, climate, etc.

Nitrogen added by means of micro-organisms.—This subject will be treated in the next chapter (p. 213).

Plant-food from subsoil.—Considerable amounts of plant-food are brought to the surface soil where plants can use it, (a) as the result of growing deep-rooted crops, (b) by means of gradually increasing the depth of plowing, and (c) through the usual upward and downward movements of the soil water, dry periods causing the soil solution to ascend to the region of growing plant-roots.

Plant-food added through purchased feeding-stuffs.—When a farmer purchases feeding-stuffs for his animals and applies the resulting manure to his soil, he obtains the double feeding and fertilizer value.

It will be noticed that, of these different methods of making up losses of plant-food constituents, the materials in most mineral fertilizers, in rain-water and in the nitrogenous products of certain micro-organisms are the only ones that are actually added to the soil, the others coming from the soil itself or the subsoil. What plant-food is applied in the form of animal or vegetable materials is simply restoration of what was previously a part of the soil.

CHAPTER XII

THE RELATIONS OF MICRO-ORGANISMS TO PLANT-FOOD

The soil was once regarded as the abiding place of non-living matter for the most part; such changes as were known to occur, especially obvious ones like the decay of organic matter in soils, were regarded as purely chemical without any relation to biological activities; but we now know that soils, especially cultivated soils, teem with unseen life, and that many of the most important chemical processes taking place within are due to the presence and action of living organisms. These living beings, though very small, are subject to the same general conditions as prevail among higher organisms in relation to the biochemical problems of nutrition, reproduction and death. Owing to the fact that the use of a microscope is required to enable one to see many of these organisms satisfactorily, they are spoken of under the very general term of micro-organisms. The relations of these microscopic beings to soil fertility form a comparatively new field of investigation, which has already yielded results of far-reaching practical value in relation to the feeding of plants. These relations appear to be of increasing importance as our knowledge enlarges. In our treatment of the subject, we shall consider some of the most interesting facts relating to the work of micro-organisms in converting unavailable into available plant-food, paying special attention to the conditions, so far as known, that enable us to control and utilize these processes in furnishing our crops with needed food. We shall consider also some of the results of the activity of certain organisms that tend to operate against conditions favorable to the welfare of plants.

The numerous micro-organisms in soils in which we are here interested may be considered under three general divisions

1. Bacteria,
2. Fungi,
3. Protozoa.

Of these general divisions of soil micro-organisms connected with the feeding of plants directly or indirectly, bacteria are, in their beneficial effects, of far greater interest, importance and promise, so far as our present knowledge goes. The fungi and protozoa to be noticed by us are more or less largely associated with processes that are harmful rather than beneficial to plants. While bacteria and fungi are regarded as belonging to the vegetable kingdom, protozoa represent the simplest form of animal life.

BACTERIA

Bacteria are the simplest and smallest known forms of plant life. Each individual consists of a single cell. On account of their power of rapid multiplication under favorable conditions, they are capable of producing very extensive chemical changes, especially in animal and vegetable materials. Before taking up a detailed study of soil bacteria, it is desirable to obtain some knowledge of their general characteristics, such as (1) size, (2) forms, (3) reproduction, (4) effects, and (5) conditions of growth.

Size.—Individual bacteria average in diameter about one twenty-five thousandth of an inch and vary from one thousandth to less than one fifty-thousandth of an inch. This means that if twenty-five thousand bacteria of average size were placed side by side, they would reach only one inch.

Forms.—Bacteria appear in three general varieties of form. Following we give the names of these, both the

common and the scientific: (1) Ball (coccus), (2) rod (bacillus or bacterium) and (3) cork-screw (spirillum). Each of these shapes varies more or less with different kinds of bacteria. In the first shape they may exist as separate balls, or in pairs, chains or square and cubical masses. Those appearing in rod-like form may be much like a lead-pencil in shape, long and slender, or they may be thick and short. The rods may be separate or they may be strung together, end to end. The cork-screw shaped variety may closely resemble a cork-screw or may be much like a comma, a letter S, or a watch-spring. There are, however, numerous variations from these regular forms. Some bacteria have one or more little threadlike, external appendages, which by working rapidly back and forth enable the organisms to move about when there is any cause for changing their location. These appendages are quite common with rod-shaped bacteria but comparatively rare with the ball-shaped.

Reproduction.—Bacteria reproduce by simple division; that is, when a cell grows in size, it increases more in one direction, so as to lengthen out slightly, and a partition forms across the cell, thus producing two new cells in place of the old one; and then each of these subdivides again, and so on continuously. In some kinds of bacteria, the whole cell is transformed into a spore, which may be regarded as bearing much the same relation to bacteria as a seed to a higher plant, or an egg to an animal. Spores are not so easily killed as are bacteria, and, therefore, spore-producing bacteria reproduce under conditions which would kill fully developed bacteria. Under favorable conditions the rapidity of growth of bacteria is almost beyond belief and wholly beyond comprehension. In some cases, one cell divides into two cells every thirty minutes; that is, passes through its cycle of life from birth to reproduction; if such a rate were kept up for twenty-four hours the one

cell would multiply into more than three hundred trillions (300,000,000,000,000). Such rapidity of increase does not occur under ordinary conditions, owing to the exhaustion of food supply, accumulation of poisonous products and the consequent death of many cells.

Effects produced by bacteria.—In the course of their growth, bacteria produce many different kinds of change in the materials in which they live; the process by which these changes are brought about is known under the general name of *fermentation*, while the causes of the change, or the bacteria, are known as *ferments*. In many cases the immediate cause of each change is a specific substance produced by the bacteria, such a substance being known as an *enzym*. While living bacteria are known as *organized* ferments, their enzyms are classed as *unorganized* ferments, which are ferments without life, or chemical substances, that are capable of causing marked changes in many complex organic compounds, the enzyms themselves undergoing little or no change. The special function of enzyms is generally to assist bacteria in procuring food. Bacteria, like the hair-root cells, take their food materials only in soluble form through the cell-walls; substances not in solution cannot pass through the cell-walls, and in such condition are useless as food. In order to utilize insoluble materials, such, for example, as cellulose and insoluble proteins, many bacteria produce enzyms within the cell, which pass out of the cell and dissolve insoluble materials that can pass into the cell for use as food. In making use of food materials, bacteria convert them into new forms of combination, producing various kinds of bacterial products, among which are sugars, acids, alcohols, soluble nitrogen compounds (peptones, amino acids, ammonia, nitrous acid, nitric acid, free nitrogen), aromatic compounds and numerous other products. Some bacterial products are intensely poisonous, while others are highly useful.

Conditions of growth.—The life and growth of bacteria are affected by a number of conditions, among which are (1) food, (2) temperature, (3) air, (4) moisture, (5) light, (6) chemical and physical surroundings, (7) products of bacterial action, (8) presence of other forms of life.

(1) *Food.*—The bodies of bacteria consist of proteins, carbohydrates, oils, etc., and, therefore, for satisfactory growth they, like higher plants, require as food soluble compounds containing nitrogen, carbon, hydrogen, sulphur, oxygen, and, in addition, small amounts of inorganic or mineral compounds (those containing phosphorus, potassium, magnesium, etc.). The compounds contained in vegetable and animal matter form the usual sources of supply of food for bacteria. Different kinds of bacteria show decided preferences for one kind or another of food compounds. For example, some thrive only on organic nitrogen, others on ammonium compounds, others on nitrite and still others on nitrate nitrogen. When bacteria live in or on some other organism and derive the nourishment therefrom, they are known as *parasites* (*para,* beside; and *sitos,* food); many plant and animal diseases are due to the parasitic action of bacteria. Bacteria which derive their sustenance from dead organic matter, as, for example, manure and garbage heaps, are called *saprophytes* (rotten plants).

(2) *Temperature.*—Different bacteria flourish best within definite narrow limits of temperature. The most favorable range of temperature for bacterial activity lies between 70° F. and 105° F. (21° and 40° C.), or, perhaps, within the narrower range of 60° to 80° F. (15.5° to 25.5° C.) for most soil bacteria; in general, activity decreases as the freezing point of water (32° F. or 0° C.) is approached, when all signs of active life cease; but intense cold, unless applied for a long time, usually does nothing more than to render bacteria inactive; on warming again, they become active. Above

110° F. (43° C.) bacteria gradually lose their vigor and many are killed at 130° to 140° (54° to 60° C.) in ten minutes, or in less time at higher temperatures. At the temperature of boiling water (212° F. or 100° C.) most bacteria are killed, but many bacterial spores are not killed except at considerably higher temperatures and may even then require one to three hours. Dry heat is less effective than moist. When bacteria are not actually killed by heat, their vitality may be greatly weakened, as manifested by diminished activity.

(3) *Oxygen.*—Bacteria vary greatly in respect to their ability to live with or without a supply of air or oxygen. Some can live only when well supplied with air; these are called *aërobes* or *aërobic.* Bacteria of this kind cause the elements of organic matter to unite with oxygen; that is, they oxidize organic matter. They are useful in making available the plant-food materials in organic matter. As we shall see later, the bacteria that cause rapid decomposition are aërobic and also those that produce nitrification, as well as certain kinds that fix nitrogen. Other bacteria soon die or cease being active if exposed to the air; these are called *anaërobes* or *anaërobic.* These take oxygen away from (reduce) organic matter, decomposing it and tending to change it to the form of gaseous compounds. Bacteria that convert cellulose into soluble compounds are anaërobic. Both aërobic and anaërobic bacteria are found in soils, manure heaps and other places. In many cases, as in manure piles, the air is used up by the aërobic and the conditions thus made suitable for anaërobes.

(4) *Moisture.*—Many bacteria become dormant on being dried, though still retaining life, and then become active again when placed under suitable moisture conditions. Some are killed at once by drying. In the decomposition of vegetable matter in soils there is said to be little bacterial action when the percentage of moisture drops below 25 per cent.

(5) *Light.*—Sunlight kills most bacteria when they are exposed directly to the sun's rays for a few hours. Spore forms are less easily affected. In the case of bacteria in soil and water, direct sunlight affects only those bacteria in the topmost layer. Diffused sunlight and artificial light may lessen the activity of bacteria.

(6) *Chemical and physical surroundings.*—The presence of an acid destroys or prevents the growth of those kinds of bacteria which flourish only in a neutral or slightly alkaline medium. Hence, a soil containing free acid or acid salts is unfavorable for some bacteria; in strongly acid condition, molds flourish instead of bacteria. Under conditions prevailing in such places as brackish swamps, humus-free soils and sand beaches, certain kinds of bacteria are not found. Many chemical compounds have the effect of either killing or checking the growth of bacteria. Those compounds that simply retard the rapidity of growth of bacteria are called *antiseptics;* those that destroy bacterial life are called *disinfectants.* The addition of acid phosphate, kainite and similar substances to stable manure is usually for the primary purpose of checking or preventing bacterial action. It may be stated further that many compounds which, in dilute solutions, serve as food, act as poisons when present in concentrated form; for example, nitrifying bacteria use soluble organic matter as food, but their activity is retarded when too much is supplied.

Certain physical surroundings are unfavorable to bacterial activity. For example, bacteria do not flourish in pure clay or sand or in soil filled with stagnant water. These are, however, connected with conditions of temperature, air supply, etc.

(7) *Products of bacterial action.*—Bacteria when active are constantly transforming chemical compounds, and these products of chemical change tend to accumulate. When they reach a certain condition of concentration,

they often act as poisons in reducing or stopping continued bacterial activity. In many cases the products of one kind of bacteria are poisonous to other kinds. To illustrate, lactic acid bacteria are the ones characteristic of sour milk; they convert the sugar of milk into lactic acid, but cease to act when about 1 per cent. of lactic acid has been formed, even though only a part of the milk-sugar is changed. Lactic acid stops the activity not only of these organisms but also that of many other bacteria that require a neutral or slightly alkaline reaction, such, for example, as act upon the insoluble protein, milk-casein, and change it into soluble nitrogen compounds. If we add to sour milk some calcium carbonate and thus neutralize the lactic acid, the bacteria will renew their activity and produce acid until the mixture contains about 1 per cent., when they will stop; but, if enough calcium carbonate is added, the action will be continued until all the milk-sugar is changed. The same is true of many soil bacteria; they produce acids until there is an accumulation sufficient to check or stop their activity, but in soils well supplied with calcium carbonate the action can go on as long as food supply and other conditions are favorable.

(8) *Presence of other forms of life.*—Recent investigations indicate that the soil may contain protozoa (p. 231) which feed upon living bacteria to such an extent as to interfere seriously with the proper performance of certain bacterial functions in the soil.

Soil bacteria.—One of the important functions of soils is to furnish a congenial living place for bacteria, especially for those forms that do useful and necessary work in connection with the feeding of crops. Many different kinds of bacteria are present in soils. Some are very useful, others are injurious, while many are apparently neither.

(1) *Distribution.*—In fertile soils bacteria are exceedingly numerous; in dry, sandy soils and those containing no humus, their numbers are few. At the surface of soils, there are comparatively few bacteria; in the upper layer, just beneath the surface, there are many, while three feet down there are only a few, and practically none below five or six feet. In open soils that permit free circulation of air, such as sandy soils and sandy loams, those organisms abound that require air (aërobic), while in heavy clay soils, in which circulation of air is limited, aërobic bacteria are not abundant but rather those that thrive in the absence of air (anaërobic). Other conditions influence the kind and number of bacteria in soils, such as food supply, altitude, exposure, plant growth, methods and extent of cultivation, kinds of fertilizers applied, drainage, liming, crop-rotation, supply of organic mater, etc. Crops with heavy foliage, such as cabbage, beets, etc. by shading the soil, affect conditions of temperature, moisture and light differently from such crops as wheat. Generally speaking, bacteria are found most abundantly in the soil where there is vegetable matter to furnish food, provided the other conditions of chemical and physical environment are favorable to their existence.

(2) *Changes produced.*—Soil bacteria effect important changes in the plant-food constituents of the soil, both mineral and organic. They are also instrumental in making atmospheric nitrogen available as plant-food. Some bacteria also convert available forms of plant-food into less available condition. The effects of various kinds of soil bacteria instrumental in producing important changes in plant-food will be discussed under the following divisions:

1. Changes in the organic soil constituents.
2. Fixation of atmospheric nitrogen.
3. Changes in the mineral soil constituents.

CHANGES IN ORGANIC SOIL CONSTITUENTS

Of the so-called organic constituents, carbon, hydrogen and oxygen are obtained from the air either directly or indirectly (p. 16) without the intervening action of bacteria, at least to any appreciable extent, so far as we now know. But the nitrogen of the air, as such, is not directly available for the feeding of plants, although it constitutes the sole and original source of supply. The means of changing portions of atmospheric nitrogen into plant-food material have depended largely upon bacteria. The nitrogen thus originally obtained from the air has been transformed into plant and animal tissues and these have gone into the soil, there to be acted upon by micro-organisms, largely bacteria, and worked over into forms which plants can use again as food. The changes by which plant and animal substances are made useful in the soil as sources of available plant-food are not only highly interesting but extremely important in their applications to practical crop growing. Thus, the conversion of the vegetable matter of green crops, of roots, and of all vegetable waste material into soil humus depends chiefly upon the action of bacteria (pp. 120-125). Likewise, the fermenting or rotting process by which the animal and vegetable materials in farm manures are profoundly changed in composition is due chiefly to the work of bacteria. The bacterial changes produced in organic matter are largely in the direction of converting insoluble into soluble plant-food material. These various changes will be considered under the following subdivisions: (1) Decomposition, (2) ammonification, (3) nitrification, (4) denitrification.

Decomposition.—The term, decomposition, is used here to cover those chemical and physical changes which vegetable and animal matter undergo when their very complex compounds (proteins, carbohydrates, etc.) are

changed into simpler compounds under the action of various living organisms, especially bacteria. The processes of bacterial decomposition vary greatly, depending on the kind of organic substance and various other conditions, but especially on the presence or absence of air; they may be divided into two general kinds: (1) Decomposition in air (aërobic), commonly known as *decay;* and (2) decomposition away from air (anaërobic), usually called *putrefaction.*

These processes are not simple either in respect to the number of chemical changes taking place or the variety of different species of bacteria taking part. We can simply outline the general results. Before considering the processes of decomposition in further detail, it may add to the clearness of our understanding if we first call attention to the general classes of compounds present in organic matter, and especially vegetable matter, which forms so large a part of the organic matter of soils. Vegetable matter may be regarded for our purpose as being made up in large part of the following general classes of compounds:

(a) Non-nitrogenous organic compounds, containing the elements, carbon, hydrogen and oxygen, which include (1) carbohydrates (cellulose, starch, sugar, etc.), (2) oils, and (3) organic acids.

(b) Proteins, which contain nitrogen as a distinctive constituent, in addition to carbon, hydrogen and oxygen; in many proteins sulphur is also present in small amounts, and phosphorus is a constituent of several.

(c) Mineral constituents (compounds of potassium, phosphorus, calcium, magnesium, sulphur, sodium and chlorine), which are always present in small amounts in organic matter.

We will now notice what chemical changes in general take place in these classes of compounds, when, for example, a vegetable substance undergoes decomposition

in air (decay) and out of air (putrefaction). The character of the chemical changes produced by each process is very different.

(1) *Decay or decomposition in presence of air (aërobic).* When leaves or grasses fall upon the ground, they are in contact with an abundance of air and in time undergo aërobic decomposition. The organic materials go through a slow process of burning, or union with oxygen, and in time disappear in the form of gases, leaving finally about the same constituents that would be found in the ashes formed by rapidly burning the same materials. When the process is complete no trace of organic matter remains. Going somewhat more into detail, the following changes occur:

(a) Non-nitrogenous organic compounds (the carbohydrates, oils and organic acids). (1) The carbohydrates, *sugar* and *starch*, are decomposed quite rapidly by various kinds of bacteria and fungi, being converted into different intermediate simpler compounds, among which are some well-known organic acids, such as acetic, the characteristic acid of vinegar. But whatever intermediate changes occur, the final products of decay are carbon dioxide and water. (2) *Cellulose*, the carbohydrate that constitutes the bulk of vegetable cell-walls, is less quickly attacked by decay bacteria than are sugar and starch. While there are several species of aërobic bacteria which can dissolve cellulose, some fungi (p. 230) are also capable, of doing the same, and, under ordinary conditions, the decay of cellulose is due to the combined action of fungi and aërobic bacteria, mainly through enzyms. The intermediate and final products of the decay of cellulose are much the same as those of sugar and starch. In connection with the decay of vegetable matter in both soils (p. 125) and manure piles (p. 313), the dissolving of the tough cellulose covering of the cells is a matter of practical value, because it sets free the various carbohydrate

and nitrogenous food constituents contained in the cells and makes them accessible to other bacteria. (3) *Oils* are changed into acids and these finally into carbon dioxide and water. (4) *Organic acids* ultimately form carbon dioxide and water. Some of the intermediate decomposition products of the non-nitrogenous organic compounds are used as food by other bacteria.

(b) Proteins. When protein compounds decay they form a succession or series of simpler nitrogen-containing compounds ((1) albumoses or proteoses, (2) peptones or peptids and (3) amino acids); sooner or later the nitrogen passes into the form of ammonia (ammonification, p. 203) with more or less formation of free nitrogen according to conditions of fermentation. The carbon, oxygen and hydrogen of proteins are finally converted into carbon dioxide and water, the sulphur into sulphuric acid and the phosphorus into phosphoric acid.

(c) Mineral constituents originally present in vegetable matter are left as a residue, comparable to ashes, mainly in the form of calcium, magnesium, potassium, sodium, etc., salts, such as phosphate, sulphate, carbonate and chloride.

(2) *Putrefaction or decomposition in absence of air (anaërobic).*—Bacteria, entirely different in kind from those causing decay and different also in the results of chemical change produced, are responsible for the process of putrefaction. This process applied to organic matter in soils is known as *humification.* The general differences in the results of the two processes can be embraced under the following statements:

(a) Putrefactive process slower. The chemical changes of putrefaction are slower than those of decay. This is shown by the difference in the rate of decomposition in organic matter in loose, as compared with close, soils, or at the surface of a soil as compared with that at considerable depths, or on the outside of a compacted

manure pile as compared with the inside, or in a well-drained, as compared with a water-logged, soil.

(b) Chemical changes less complete. In putrefaction the chemical changes do not go so far as in decay; the complex organic compounds, whether nitrogenous or non-nitrogenous, are not so completely decomposed into very simple compounds. While some carbon dioxide, water and ammonia are formed, the carbon, hydrogen, oxygen and nitrogen are more largely found in the form of intermediate compounds of considerable complexity of composition, as illustrated by the dark-colored compounds present in soil humus (p. 117).

(c) Putrefactive products resistant to further change. The dark-colored, intermediate organic compounds formed by putrefaction are not easily decomposed by other bacteria, even when exposed to air, as already explained in connection with organic matter in soils (p. 122).

(d) Offensive and poisonous compounds. Many of the compounds formed by the putrefaction of organic matter, and particularly of nitrogenous substances containing sulphur and phosphorus, are peculiarly offensive in odor, and many of them are poisonous, among which are the following compounds: Hydrogen sulphide or gaseous sulphureted hydrogen (H_2S), phosphine or gaseous phosphureted hydrogen (PH_3), skatol and indol (furnishing characteristic odors in human excrements), etc. These compounds as well as many other putrefactive products are poisonous.

(e) Difference in gases formed. While in putrefaction there are formed some of the same gases that are formed by decay, such as carbon dioxide, water, ammonia and nitrogen, they are formed in much smaller amount, while other gases are present which do not occur appreciably, if at all, in decay, such as marsh gas (CH_4), phosphine, hydrogen sulphide, etc.

The general process of decomposition of organic matter in soils, whether decay or putrefaction, is one of extreme complexity, owing to the variety of conditions which influence one or another kind of bacterial activity. In each kind of decomposition many different kinds are at work at one time or another. While the chemical changes during the processes of decomposition go through a certain kind of orderly progression, we find many of the changes in the different classes of compounds going on at the same time under the action of many different kinds of bacteria, working approximately side by side, the products of some retarding or hastening the activity of others. The most that we can hope to do profitably here is to call attention, as we have done, to the general character of the process and the final results, in so far as they have some application to questions of crop-feeding.

Ammonification is a term applied to the general process by which organic or protein nitrogen is converted into ammonia. We have already seen that, in the decomposition of organic matter, the nitrogen compounds are sooner or later changed into ammonia partly or completely; and we can, therefore, regard ammonification as essentially the process of decomposition, limited to protein compounds, under conditions favorable to the formation of ammonia, this product being the result of the last stage of the decomposition of nitrogen-containing organic compounds or proteins. The production of ammonia from proteins or their decomposition products is accomplished by many kinds of bacteria, known comprehensively as *ammonifying* bacteria; some of them are aërobic, others anaërobic. The various kinds differ in their chemical processes and rapidity of action in producing ammonia from proteins and their derived products. The formation of ammonia from organic nitrogen compounds in soils depends upon a variety of conditions, such as the kind of

It is to be kept in mind that the nitrification process results in producing an acid, which calls for some constituent to combine with and neutralize the acid properties, if the best conditions for further formation of nitrate nitrogen and for the growth of plants are to be maintained. For example, each pound of nitric acid formed calls for nearly a pound of calcium carbonate.

(2) *Character of bacteria of nitrification.*—The nitrous ferments, or bacteria capable of changing ammonia into nitrous acid, are known under the names *nitroso-monas* and *nitroso-coccus.*

The nitric ferments, or bacteria that effect the change of nitrous acid (HNO_2) into nitric acid (HNO_3), are known under the name of *nitro-bacter.* These two groups are together often called *nitrifying bacteria* or *nitrifiers.*

The nitrous and nitric organisms appear to be influenced, in large measure, by the same conditions, favorable and unfavorable, and, therefore, are usually found working together, because nitrous acid, almost as rapidly as it is formed from ammonia, is changed into nitric acid; and it is only under abnormal soil conditions that we find appreciable amounts of nitrous acid.

It may be added here that there has been recently reported the discovery of a micro-organism that can convert ammonia directly into nitric acid without the intermediate formation of nitrous acid.

Nitrifying bacteria are found in all cultivated soils, in water, in manure, and in sewage. They are not abundant in soils that are either excessively poor or excessively rich in organic matter as, for example, in forest soils, muck deposits, arid deserts, etc. It is an interesting fact that in soils of high productive power the nitrifying ability of the bacteria is often greater than in the case of the nitrifying bacteria from soils of less productive power.

While much remains to be learned in regard to the conditions under which nitrifying bacteria work with

greatest efficiency, we know many facts regarding the soil conditions that favor or retard the process. It is a matter of practical importance to know something of these conditions and we shall, therefore, briefly consider the following points in this connection: (a) Location, (b) moisture, (c) food, (d) oxygen, (e) temperature, (f) light, (g) non-acid condition.

(a) Location. Nitrifying bacteria are most numerous in the upper layers of soils, because the conditions are there most favorable for their growth. Probably two-thirds of the nitrate nitrogen produced in soils is in the first foot of the upper surface and the remainder is in the next foot below. The depth at which these bacteria occur depends upon the looseness and warmth of the soil.

(b) Moisture. In a dry soil nitrification does not take place. Therefore, in periods of drouth, this important process is apt to cease in the upper layers of soil. In a wet soil, on the other hand, where water is stagnant, this process does not occur actively.

(c) Food. The nitrogen of organic matter in soils forms the primary source of nitrogenous food for the nitrifying bacteria; in the more limited sense of nitrification, ammonia constitutes the nitrogen food supply. The complete absence of organic nitrogen does not stop the process of nitrification so long as there is a supply of ammonia. It is possible, however, to have so much soluble organic nitrogen present that the nitrifying organisms will stop growing, as in the case of a manure pile. An excess of soluble carbohydrate material also interferes with their activity. In cultivated soils we rarely find so much organic matter present as to interfere with the process of nitrification, even when applications of 20 tons of farm manure per acre are applied two or three years in succession; interference may happen in greenhouse and market-garden soils, where immense applications of stable manure (50 to 100 tons an acre)

are often made. The use of sewage-irrigation also furnishes a striking illustration of the effect of soluble organic materials on nitrification. Phosphoric acid compounds are also essential for the satisfactory growth of these organisms and probably also potassium and other mineral compounds.

(d) Oxygen. It has been already pointed out that the process of forming nitrous and nitric acids from ammonia consists essentially in adding oxygen to nitrogen in chemical combination. Hence, nitrifying organisms cannot work vigorously without a generous supply of air. For this reason they are most abundant in those layers of the soil where there is most air. Water-saturated soils prevent nitrification by shutting off the air. Limited air supply is one of the important factors which explains slow nitrification on heavy sod land and in clay soils. All operations connected with the cultivation of soils greatly promote the change of ammonia into nitrate nitrogen, because the oxygen of the air is brought into closer contact with the nitrifying bacteria.

(e) Temperature. Nitrifying bacteria are most active between the temperatures of 54° and 99° F. (12° and 37° C.). The process may go on slowly as low as 37° F. (3° C.) and as high as 120° F. (49° C.). Activity rapidly increases with rise of temperature above 54° F. (12° C.), so that at 99° F. (37° C.) nitrification takes place about ten times as rapidly as at 54° F. (12° C.). In northern latitudes, nitrification slows down during the fall and stops during the winter, starting up again in spring and becoming most active during midsummer. In warm climates, the process continues at all times of year. Crops start earlier in spring on light soils because the greater warmth of such soils favors the more rapid formation of nitrate, which promotes early growth of crops.

(f) Light. Darkness is essential to the activity of nitrifying bacteria, since the direct rays of sunshine destroy bacterial life. These organisms are, therefore, not found on the exposed surface of soils as, for example, on the surface of bare fields. They are more active in soil shaded by growing crops than in unprotected soil. Nitrification is promoted on warm nights, and in warm dark places, as under boards, stones, etc.

(g) Non-acid condition. Nitrifying bacteria are extremely sensitive to acids, which act injuriously like poisons on these organisms. We have seen that the final product of nitrification is free nitric acid, which, if allowed to accumulate without being neutralized, stops further nitrification. Similarly, in the presence of any other free acid, nitrifying bacteria fail to work. Nitrification cannot, for this reason, take place in acid or sour soils. In order that there may be no accumulation of free nitric or other acids in soils, it is absolutely necessary that there shall be an abundance of some basic compounds, which can unite with the free acids and form salts that do not act injuriously on nitrifying organisms. The compound most available for neutralizing acids is calcium carbonate, though the carbonates of magnesium, potassium, sodium, etc., are efficient when present. With calcium carbonate and nitric acid, there are formed calcium nitrate, carbon dioxide and water (p. 205). Such compounds as nitrate of calcium, magnesium, sodium, etc., even when present in considerable quantities, are not injurious to nitrifying bacteria. It is, therefore, highly important to keep agricultural soils well provided with acid-neutralizing or basic materials in order to favor the formation of nitrate nitrogen. When slaked lime (calcium hydroxide) is applied to soils in amounts so large as to make the reaction of the soil solution distinctly alkaline, the action of nitrifying bacteria is suspended for a while, but it will begin again when the

calcium hydroxide has been changed into carbonate and the alkaline condition thereby changed to neutral.

Denitrification.—The bacterial process of denitrification, chemically considered, produces results just the reverse of those produced by nitrification. Nitrification, as we have seen, is an oxidation process; it consists in adding oxygen to nitrogen, by which there is first formed nitrous acid and then nitric acid. Denitrification, on the other hand, is a *deoxidation* or *reduction* process; it consists in taking oxygen away from nitric acid (HNO_3), by which there is first formed nitrous acid (HNO_2) and then either ammonia (NH_3) or free nitrogen gas (N). There is also another form of denitrification by which oxygen is removed and the nitrate nitrogen is changed into insoluble organic nitrogen compounds or proteins. These three general forms may, for our purpose, be represented in the following general manner:

(1) Destructive denitrification: (a) Nitric acid (HNO_3), (b) nitrous acid (HNO_2), (c) nitrogen gas (N).

(2) Partial decomposition: (a) Nitric acid (HNO_3), (b) nitrous acid (HNO_2), (c) ammonia (NH_3).

(3) Conversion into organic nitrogen compounds: (a) Nitric acid (HNO_3), (b) protein compounds.

The term denitrification strictly applies only to the first or destructive form, the process by which nitrate nitrogen is changed into uncombined or free nitrogen gas, which in this form is lost as plant-food to soil and crops. When nitrate nitrogen is converted into nitrous acid or ammonia or organic nitrogen, these compounds remain in the soil, and, under favorable conditions, are again changed back into nitrate nitrogen.

Quite generally in soils and in animal manures and on straw there are found several different kinds of bacteria which have the power to cause decomposition of nitrate nitrogen in one of the ways mentioned. It is desirable to

know something of the conditions under which the destructive form occurs and thus learn how we may avoid large losses of nitrate nitrogen. Two general conditions favor the process of denitrification: (1) Lack of air and (2) superabundance of soluble organic matter.

(1) *Lack of air in relation to denitrification.*—Denitrifying bacteria require some oxygen for their activity, and when this need is not supplied by air, they take the nitrogen from the nitrates in the soil. This fact affords an explanation of the destruction of nitrate nitrogen in the lower layers of soils, as well as in surface soils that are saturated with stagnant water. It explains also why heavy, compact soils tend to suffer loss from denitrification to a greater extent than open, sandy loams. Of course, no denitrification can occur, even in the absence of air, when the soil contains no nitrate and no readily decomposable organic matter. Any condition that promotes circulation of air in soils, such as thorough tillage, good drainage and application of lime, diminishes the danger of denitrification. In the use of fertilizers it is obvious that the application of a nitrate to a soil in which, for any reason, the supply of air is deficient is in danger of being followed by destruction of the nitrate nitrogen and loss as free nitrogen.

(2) *Superabundance of organic matter in relation to denitrification.*—An important condition for active denitrification is the presence of an abundant supply of soluble organic matter in soils. When large amounts of nitrate are applied to soils along with an excessive quantity of fresh farm manure, there is likely to be large loss of nitrate by denitrification. Similar loss may come from plowing under heavy crops of green-manures. At one time it was supposed that the losses of nitrate through denitrification were rather common under usual agricultural conditions, but recent investigations have shown that extensive losses of soil nitrate from denitrification

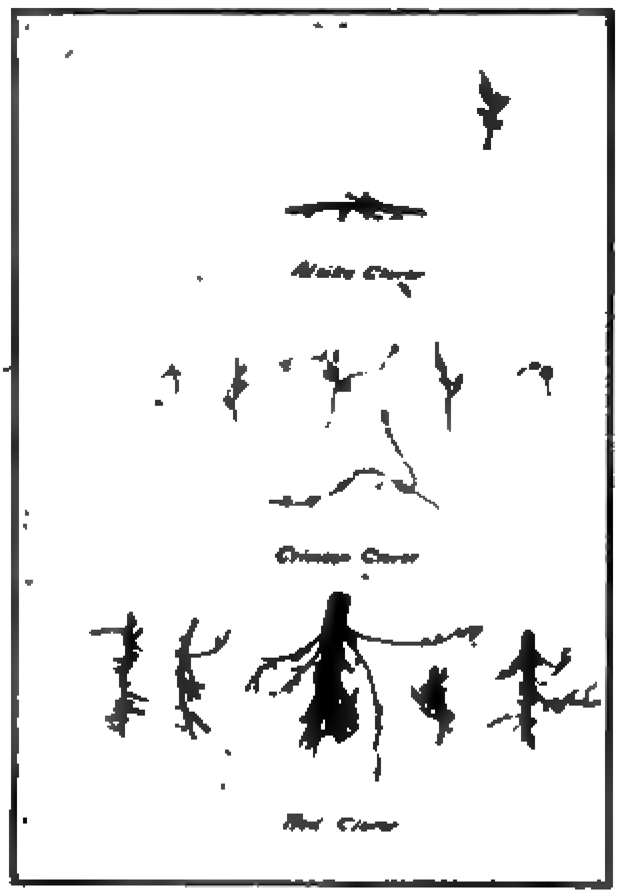
need not be feared under ordinary conditions of practice, provided good drainage and tillage are maintained. Generous applications of partly rotted farm manure along with nitrate may cause no loss when the soil is kept well supplied with air. Denitrification becomes a source of serious loss only under certain conditions, as when a large amount of nitrate is applied to undrained or sour land, or when used with excessive amounts of fresh farm manure, or whenever large amounts of fresh organic matter accumulate in the soil.

Before leaving the subject of denitrification, it may be well to say something more about the conversion of soluble nitrogen compounds (nitrate, nitrite, ammonia, organic compounds) into insoluble organic form, though this process is not regarded as one of denitrification proper. All bacteria, like other plants, require some nitrogen as an essential constituent of their bodily substance. In supplying this need, they take soluble nitrogen compounds and convert them into the insoluble organic substances which form part of their bodies. It is inevitable, therefore, when such processes as decay, putrefaction, ammonification, nitrification, denitrification and many others are going on actively in soils, that the bacteria increase in large numbers and that all these organisms are appropriating for the growth of their own bodies soluble nitrogen compounds which are changed into insoluble organic nitrogen compounds. Under favorable conditions of growth, the enormous increase of bacteria present in a soil may in this way render insoluble fairly large amounts of soluble nitrogen. Nitrogen which is thus taken from soluble forms is held for the most part until the bacteria die and their bodies go through the process of decomposition, yielding again ammonia and nitrate. This process is one that may be desirable under conditions where considerable nitrate accumulates in a soil and is in danger of leaching before being used by

crops. The change of nitrate into insoluble organic compounds then serves to hold it for future use and decreases loss by leaching.

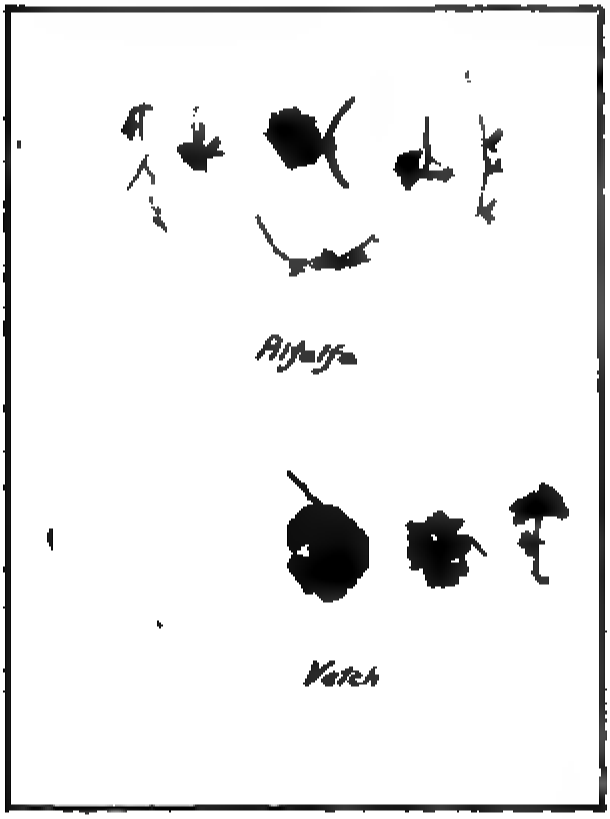
FIXATION OF ATMOSPHERIC NITROGEN

We have seen that certain kinds of bacteria have the power of changing various nitrogen compounds in soils into nitrate nitrogen by the process of nitrification. Nitrification does not, however, increase the total amount of nitrogen present in a soil. The amount of nitrate produced is strictly limited to the amount of nitrogen compounds in the soil; no more nitrogen is present in the soil after than before the process. The form of combination is changed; that is all. But there are other kinds of bacteria which have the ability to add nitrogen to the soil's supply by taking the gaseous atmospheric nitrogen and transforming it into combined forms of nitrogen that can be used as plant-food. The process by which atmospheric nitrogen gas is converted into



Root-nodules, characteristic of different plants, produced by nitrogen-fixing bacteria. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

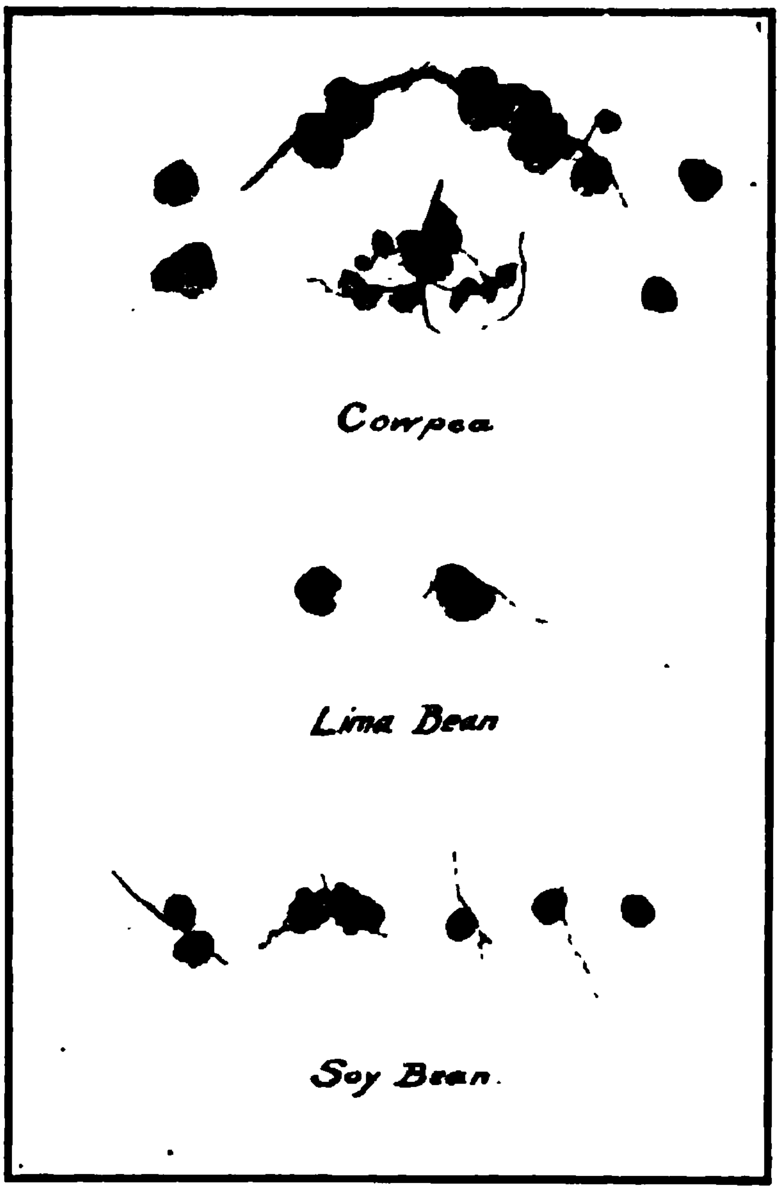
organic nitrogen compounds, useful as plant-food, is known as *nitrogen fixation*. The free nitrogen of the atmosphere can undergo fixation through the action of two general classes of nitrogen-fixing or nitrogen-gathering bacteria: (1) Those bacteria that live in the soil itself, independent of the presence of growing plants, and (2) bacteria that are dependent upon the presence of certain higher plants, living and working within the plant-roots Those in the first class are known as *non-symbiotic;* those in the second class as *symbiotic*. The word symbiotic means *living together* and is applied to cases where two different organisms live together in mutual relations that are of advantage to both. We will now consider in more detail the characteristics of both kinds of nitrogen fixation.



Root-nodules, characteristic of alfalfa and vetch, produced by nitrogen-fixing bacteria. Bureau of Plant Industry, U. S. Dept. of Agr.

Nitrogen fixation by independent or non-symbiotic bacteria.—It has been shown that soils lying unused either without any vegetation or covered with grass, will accumulate appreciably increased amounts of nitrogen in the course of one or two years. This fact has been explained by the discovery that certain bacteria living in soils are able to make the atmospheric nitrogen contained in the soil combine with other elements and

remain in the soil in a stable form. Some years ago, in Germany, such an organism was placed on the market under the name of "Alinit" in the form of a commercial culture, which was intended to be used to inoculate soils for the purpose of fixing large amounts of atmospheric nitrogen. The results of its use were thoroughly disappointing in practice, although it was found to promote the decomposition of slow-acting compounds of nitrogen, such as occur in humus. Much remains to be learned in regard to these bacteria before we can make intelligent use of their ability to fix nitrogen. So far as we now know, they do not appear to play any great part in providing soils with a store of combined nitrogen. It is known (1) that these organisms require generous supply of carbohydrate material, (2) that the presence of calcium or magnesium carbonate is important, (3) that some soluble phosphate is also needed, and (4) that the organisms are injuriously affected by an acid condition.



Root-nodules, characteristic of different plants, produced by nitrogen-fixing bacteria. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

Nitrogen fixation by dependent or symbiotic bacteria.— The practical experience of hundreds of years led farm-

ers to believe that leguminous crops (clovers, alfalfa, beans, peas, etc.) possess some peculiar power in making succeeding crops grow more successfully. This belief has, during the past generation, been shown to have a basis in fact. We can now explain why leguminous crops are of such value as has been claimed. The benefit noticed was first traced to the fact that the amount of nitrogen in a soil can be definitely increased by the growth of leguminous plants, and it was learned also that the free nitrogen of the air can be made use of by such plants. Leguminous plants contain in both tops and roots large proportions of nitrogen compounds, as compared with most other plants. It has been shown that the ability of leguminous plants to utilize the free nitrogen of the air depends upon certain kinds of bacteria, which we will study briefly under the following heads: (1) Root-nodules and bacteria, (2) relation of bacteria and legumes, (3) amount of nitrogen taken, (4) varieties of legume bacteria, (5) conditions of action of legume bacteria, (6) independent action of legume bacteria, and (7) nitrogen-fixing root-nodules in relation to non-leguminous plants.

(1) *Root-nodules and bacteria.*—If we carefully remove from the soil the roots of a vigorous leguminous plant, we shall usually find distributed on various portions of the younger roots little ball-like bunches, which are called *nodules* or *tubercles.* They vary in characteristic size and shape on different kinds of plants. For example, on red clover, they are quite small (from the size of a pin-head to that of a pea) and more or less ball-shaped, while on the cowpea and soy-bean they are much larger, and on the velvet-bean they may even reach the size of a baseball; on vetches they vary irregularly in both size and shape. These root growths were noticed and described over two hundred years ago, but their true nature was

not understood until about twenty-five years ago. The nodules have been shown to be the dwelling-place of the nitrogen-fixing bacteria characteristic of leguminous plants, many millions of bacteria occupying each tubercle. The tubercles are not only the dwelling-place of bacteria, but they are the direct result of bacterial action; when there are no legume bacteria, there are no root nodules, and there is no utilization of free nitrogen by the plant.

The legume bacteria are comparatively common in soils, especially where leguminous crops have grown well; they are found also in the water of streams and lakes. The bacteria gain an entrance into a plant-root by first working their way through the thin cell-wall of a root-hair, and then they make their way into and through the tissues of the nearest root-branch, where they multiply rapidly and accumulate in enormous numbers, causing the growth of the nodule for their accommodation. Root-nodules are, in reality, rootlets developing in abnormal forms on account of the presence of nitrogen-fixing bacteria within their cells. Nodules are found only on the younger parts of roots. When legumes

Root-nodules, characteristic of field-pea and garden-pea, produced by nitrogen-fixing bacteria. Bureau of Plant Industry, U. S. Dept. of Agr.

mature, the root-tubercles decay and any bacteria remaining in them go back to the soil, where they remain, if conditions are favorable, until an opportunity comes to enter again the roots of a new leguminous crop.

(2) *Relation of bacteria and legumes.*—The relation of nitrogen-fixing bacteria to leguminous plants is one of mutual helpfulness or of real symbiosis (living together). The bacteria require for their nourishment considerable amounts of sugar or other soluble carbohydrate and also mineral salts, which are generously supplied in the plant juices of legumes; the bacteria, in some way not yet understood, supplement this food supply with nitrogen taken from the air present in the soil, which they build into nitrogen compounds within their cells. It is supposed that the nitrogen compounds thus manufactured by the bacteria are diffused through the cell-walls and absorbed into the general circulation of the leguminous plant, where they are used for the building of the protein compounds characteristic of legumes. It is thus seen that the leguminous plants furnish the nitrogen-fixing bacteria needed food and home, and the bacteria reciprocate by changing free nitrogen, which is unusable

Root-nodules characteristic of velvet bean. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

directly by legumes, into usable nitrogen compounds, which it passes over to the plant in exchange for the bacterial food and lodging.

(3) *Amount of atmospheric nitrogen gathered by bacteria.* It has been shown that through the growth of leguminous crops under most favorable conditions, one may thus add to an acre of land from 100 to 200 pounds of nitrogen in one season. In many cases the amount may be 50 pounds or less when all conditions are not favorable. In some cases, the amount of nitrogen remaining in the roots and stubble, after the removal of the crop-producing portion, has been found to be quite equal to the amount of nitrogen furnished by the soil, which means that the amount of nitrogen removed by the harvested crop is equal to the nitrogen obtained from the air. Under such circumstances, the soil is no poorer in nitrogen for the growth and removal of the crop after the nitrogen in the crop residues has again become available through decomposition and nitrification. In other words, it is possible to make legume bacteria furnish from the air practically all of the nitrogen in the harvested portion of the crop. While the relative amounts of nitrogen taken by legume crops from the soil and from the air vary greatly according to many conditions, such as the kind of legume, the number of nitrogen-gathering bacteria in the soil, the amount of nitrogenous plant-food in the soil, seasonal conditions, etc., it may be stated that under favorable conditions approximately one-third of the crop's nitrogen is taken from the soil and two-thirds from the free atmospheric nitrogen.

The effect of an abundant growth of root-nodules is not always in the direction of increasing a leguminous crop on a fairly fertile soil, but they may increase markedly the percentage and total amount of nitrogen in the crop and so increase its value as plant-food in the form of green-crop manure. The percentage of nitrogen in

root-nodules is generally high as compared with other portions of the plant.

(4) *Kinds of nitrogen-fixing legume bacteria.*—For some years it was supposed that the root-nodules on all leguminous plants were produced by only one organism, known under the names, *Bacillus radicicola* and *Pseudomonas radicicola.* The question has been raised as to whether this species is the only one in all legumes, or whether there is a different species for each legume, or whether there are merely different varieties or strains. Without considering these questions in detail, it is sufficient for our purpose to know that in practice it has been found, for example, that the bacteria that promote the growth of nodules on clover roots do not form nodules on roots of alfalfa, cowpeas and most other leguminous plants. It appears, in general, that the bacteria that grow on the rootlets of one kind of legume are not well suited to the growth of other legumes, and that, therefore, best results are obtained when, for example, organisms growing on clover are used for that crop, those growing on alfalfa for alfalfa, etc. There are some cases in which the same organism appears to work equally well for different, closely related legumes. Thus, alfalfa, bur clover and sweet clover appear to use the same organisms; white and alsike clover apparently use the bacteria of red clover; the different vetches appear to use the same organism in common.

Root-nodules, characteristic of alder, produced by nitrogen-fixing bacteria. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

(5) *Conditions of action of legume bacteria.*—The soil conditions that in general favor nitrification also favor the

presence of nitrogen-fixing legume bacteria, such as abundance of calcium carbonate, organic matter, air and moisture. Soils ill-drained, acid, lacking in organic matter tend to weaken or destroy the bacteria. The nodule-forming bacteria require abundance of sugar or other carbohydrate food, soluble potassium and phosphorus compounds, but they develop to best advantage when provided with a minimum supply of available nitrogen compounds. The bacteria can and do utilize available forms of nitrogen compounds, when within reach, in preference to using free nitrogen. Therefore, when supplied

FORMS OF BACTERIA IN ROOT-NODULES

with available nitrogen compounds, the bacteria fail to make use of atmospheric nitrogen; and, in order to make them use free nitrogen, it appears to be necessary to deprive them of available nitrogen compounds. Moreover, it is found that in a soil containing an abundance of available nitrogen, or in one to which a nitrate has been generously applied, the formation of root-nodules is prevented in part or entirely. It follows, as a matter of practical application, that the nitrogen-gathering powers of legume bacteria are fully realized only when the

soil contains a minimum amount of available nitrogenous plant-food, other conditions being favorable.

(6) *Independent action of legume bacteria.*—It has been

. Crimson clover plants. Inoculated and non-inoculated. The severed root system of each is also shown. ALABAMA STATION.

apparently shown that bacteria from the root-tubercles of legumes are able to fix free nitrogen even when they are growing independently in the soil and are not connected with leguminous plants, but the amount of nitro-

gen thus fixed is small compared with that fixed when the bacteria work in the root-nodules of leguminous plants.

(7) *Nitrogen-Fixing root-nodules in relation to non-leguminous plants.* It has been found that root-nodules containing nitrogen-gathering bacteria are not confined to the Leguminosæ but occur on some plants ouside this family, such, for example, as the alder *(Alnus crispa)*, the New Jersey tea *(Ceanothus americanus)*, buffalo berry *(Lepargyrea canadensis)*, silver berry *(Eleagnus argentea)*, mountain balm *(Ceanothus velutinus)*, sweet fern *(Comptonia peregrina)*, and some members of the cycad family. These plants are not ordinarily adapted to use as a means of acquiring atmospheric nitrogen in agricultural soils, because they have little or no value as money crops. One way in which they can be utilized is in the case of unused lands where accumulation of nitrogen is desirable for future use.

Soil inoculation for legumes.—Can the use of nitrogen-fixing legume bacteria be made a practicable means of furnishing nitrogen to crops in place of nitrogen compounds obtained from commercial sources? That this can be done has been satisfactorily demonstrated; the methods that have been successfully used we will consider in detail in connection with green-crop manures (p. 351). Here we confine our attention chiefly to a single one of the requisite conditions, viz., the method of supplying to leguminous crops the nodule-forming bacteria.

In many cases, the special kind of bacteria needed is present in soils. This is true where a given legume has been grown successfully for years. For example, in the central and eastern states, the bacteria peculiar to the clovers are common in most cultivated soils, because these crops have been generally grown for a long time. Similarly, alfalfa in the western, and cowpeas in the southern, states can be grown often without making any

special effort to supply the soil with the required bacteria. On the other hand, alfalfa in the eastern states commonly requires an artificial supply of its bacteria on soils where it is grown for the first time, and the same is true of soy-beans.

It has been demonstrated that, when failure to grow a leguminous crop is due to the absence of the nitrogen-fixing bacteria characteristic of the particular crop, good

Growing alfalfa in ordinary farm soils without fertilizer. In those cases where the growth is least, there was no inoculation of the soil with alfalfa organisms; in the other cases (marked Bac.), the soils were inoculated. ILLINOIS STATION.

crops can be produced as the result of furnishing the soil with the required organisms. Supplying a soil with bacteria is known as *inoculation*. This can be accomplished in different ways, among which are the following: (1) By use of soil containing desired bacteria and (2) by use of special preparations or pure cultures.

(1) *Inoculation by use of soil.*—The most effective method of soil inoculation is to use soil taken from a field on which has been growing a clean, thrifty crop,

well provided with root-nodules, of the kind one desires to raise. For inoculating soil in case of alfalfa, either alfalfa or sweet-clover soil may be used. In obtaining the inoculating soil, one removes the upper layer of earth for two or three inches and takes the soil-below this for several inches, or that portion of the soil in which the root-nodules are most plentiful. The amount of soil used for inoculation is usually 200 to 500 pounds an acre. This is applied in any convenient manner to the surface of the field to be inoculated and should be harrowed into the upper layer of the soil promptly, because, as previously stated (p. 195), bacteria are injured or killed by exposure to direct sunlight. The disadvantage of this method of inoculation is the possibility of carrying undesirable weeds and germs of plant diseases from one soil to another. The precaution should always be observed, therefore, to use only soil from a field free from such defects. It is obvious that only soil can be used advantageously for inoculation which is in fine tilth and easily permits reducing to fine powder.

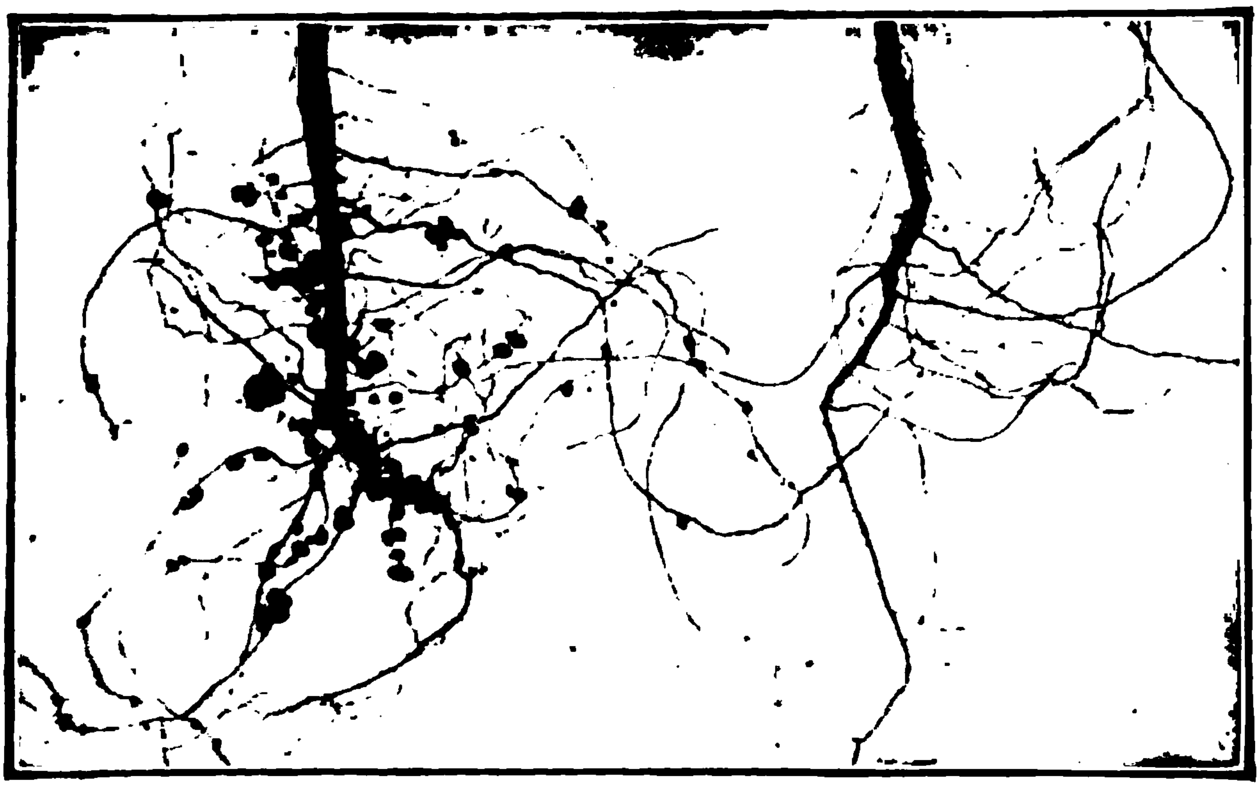
Another method of using soil for inoculation is to treat it with water and soak the seed in this water-extract just previous to sowing. Another plan, useful especially in case of large seeds, is to moisten the seeds with a 10 per cent. solution of glue and at once sift over them a coating of dry, powdered, inoculating soil. The seeds are shoveled over a few times, screened to keep them from sticking together, and planted within a day; or they may be spread out to dry and kept away from direct sunlight if it is desired to prepare them some time before planting.

Sometimes the root-nodules are gathered and sowed on soil to be inoculated. Their use is often attended with failure, because dead nodules are taken containing too few bacteria. When this method is tried, only living

Effect of inoculation on yield of soy-beans. The plant on the left came from a plot where all the plants had nodules on roots; the other from a plot where practically none of the plants had nodules. The yield was in the ratio of the size of the plants shown in the illustration. College of Agriculture, Ohio State Univ.

nodules should be used, or those taken from the roots of a plant in its full vigor of growth before maturing.

(2) *Inoculation by pure cultures.*—A pure culture is a preparation of one kind of micro-organisms, free from the presence of every other kind. Some years ago a commercial preparation, consisting of a pure culture of nodule-forming bacteria, was placed on the market under the name of *nitragin*. Its use proved generally disappointing. Many other efforts have been made in the United States to prepare cultures for each of the leguminous crops and numerous commercial preparations



Root-tubercles on soy-beans. The left inoculated and the other uninoculated. Tubercles appear only when the proper bacteria are present in the soil. College of Agriculture, Ohio State Univ.

are offered for sale. The difficulty to be overcome is to prepare the pure cultures of legume bacteria in such a way that they will remain alive and retain their full vigor for a reasonable length of time. Pure cultures are used by making application directly to seed. While the use of pure cultures has gone far enough to indicate great promise, the most reliable method of inoculation at the present time appears to be that of using proper soil.

Unfortunately, there has been widespread popular misunderstanding in regard to the real use and value of nodule-forming bacteria, owing to inaccurate statements by non-scientific magazine writers and also to exaggerations of commercial concerns dealing in so-called pure cultures, and, in addition, to over-enthusiastic claims by some scientific workers. Inoculation is not a means of providing crops with a complete fertilizer, as some have been led to believe; it simply helps, under certain conditions, to add to a crop's available nitrogen supply. Under some conditions, it is a marked success, so far as use of atmospheric nitrogen is concerned; under other conditions, it is a complete failure. Inoculation is only one of several factors necessary to the successful growth of leguminous crops; practically all other conditions essential for the growth of any crop are required.

Soil inoculation may be expected to give good results on soils that are well aërated and abundantly supplied with available phosphorus, potassium, calcium and other mineral compounds: (a) Where leguminous crops do not grow well, (b) where the roots of such crops do not have nodules, or (c) where a leguminous crop is to be grown for the first time.

Soil inoculation usually fails to produce results: (a) Where the leguminous crop inoculated flourishes already, (b) where the soil is acid, (c) where the supply of available potassium and phosphorus compounds is deficient, (d) where the soil is supplied with too much available nitrogen, (e) where the physical conditions of the soil are unsatisfactory in respect to texture, aëration, drainage, etc., or (f) where seasonal conditions are not favorable.

CHANGES IN MINERAL CONSTITUENTS BY SOIL BACTERIA

Through direct action of bacteria or through the action of their products, extensive chemical changes are brought

about in the mineral constituents of soils, as well as in substances applied to soils in the form of fertilizers. Attention has already been called to the fact that acids of various kinds are prominent among the products of the bacteria causing decay, putrefaction, nitrification, etc. The most common acid product is carbon dioxide gas, while in addition there are formed nitrous, nitric and sulphuric acids, and numerous organic acids. Carbon dioxide, when dissolved in water, and all free acids formed by bacterial action are able to bring about the following changes: (1) Calcium and other insoluble carbonates are made soluble. (2) Insoluble soil phosphates are made soluble, as well as insoluble phosphates applied in the form of ground rock (floats), ground bone, slag phosphate, farm manure, ground fish, tankage, tobacco stems, green-crop manure, etc. (3) In some cases, bacteria use soluble phosphorus compounds in building their bodies and thus convert them into insoluble organic forms, which are later restored to soluble condition by the death and decomposition of the bacteria. (4) Insoluble potassium compounds are made soluble.

Bacteria produce changes in various other soil constituents, but we can give attention to only one of these, namely, sulphur compounds. Thus, in the decomposition of vegetable and animal matter, the contained sulphur is converted into hydrogen sulphide gas, which may be changed by other bacteria into sulphuric acid. Certain other bacteria have the power to change hydrogen sulphide into free sulphur, particles of which can be seen in their bodies, when examined under a microscope; these sulphur particles are later changed into sulphuric acid. Sulphuric acid, whenever formed, may combine with some of the soil constituents to form sulphates of calcium, magnesium, potassium, etc. In some cases the sulphur in calcium sulphate (gypsum) is changed into

hydrogen sulphide gas by anaërobic bacteria that are widely distributed in soils, lakes and water.

These statements serve to show that extensive and far-reaching chemical changes are wrought by bacterial action. It is obvious that the more favorable the soil conditions are for the growth of bacteria, the more intense will be their activity and the greater the changes brought about.

RELATIONS OF FUNGI TO SOILS

The microscopic plants known as fungi, commonly called molds, are plants considerably larger and more complex in structure than bacteria. Fungi are of interest in connection with soils on account of their relations to processes of decomposition and to various forms of plant disease.

Many soil fungi assist in decomposing organic matter, especially in the early stages of decomposition. They are particularly active in acid soils in which many bacteria cannot work. They can convert insoluble into soluble nitrogen compounds. They can also convert soluble nitrogen compounds into the insoluble protein of their own bodies and so temporarily reduce the amount of available nitrogen in soils, though they give it back again when they die and undergo bacterial decomposition. When farm manure is allowed to become loose and dry, bacterial action is replaced by that of fungi, an undesirable condition commonly known as "fire-fanged," in which the manure is so permeated with the fungous growth as to look white and dusty.

Recent investigations indicate that certain forms of fungi show well-developed capacity for fixing nitrogen when fed glucose. In the case of forests, the starch in the fallen leaves of autumn is changed into glucose by bacterial action and this glucose is used by certain fungi in fixing considerable amounts of nitrogen.

Fungi injurious to plants usually attack the seeds or roots. The disease of turnips and similar crops known as "finger-and-toe" and "club-root" is caused by a fungus. It is common in acid soils and is prevented by neutralizing the acidity with calcium carbonate.

Attention has very recently been called to the fact that there are several kinds of fungi destructive to flax, wheat, oats and barley, which are found in both soil and seed. The action of these fungi, it is claimed, explains "wheat-sickness," "flax-sickness," etc., on older soils where these crops have been grown extensively. The extent of damage produced depends upon weather conditions, methods of handling soil, kinds and amounts of fertilizers applied, etc. Decreased crops of inferior quality are believed to be due to these fungi rather than to lack of plant-food or physical conditions of soil except as the latter factors may directly affect the conditions that influence the growth of the fungi. Beneficial effects of soil sterilization are said to be due to the destruction of these fungi. The remedies for these fungous diseases are, in general, crop rotation, treatment of seed by disinfection to destroy fungi, and observance of all precautions necessary to prevent the spread of the fungi. Whether the action of these fungi actually accounts for all of the troubles claimed or whether it is only one of numerous factors will require additional proof before it can receive anything like general acceptance as one of the chief causes of infertility of soils.

RELATIONS OF PROTOZOA TO SOILS AND CROPS

Protozoa are the simplest forms of animal life, consisting of single cells, but much larger than bacteria and differing from them in certain fundamental ways. Until quite recently, these organisms have not been supposed

to be in any way associated with questions of plant-food supply. The fact was observed in laboratory experiments that the crop on a soil may be doubled if the soil has been first heated to a temperature of 160° to 212° F. (70 to 100° C.) for 2 hours, while treatment for 48 hours with the vapor of chloroform or other antiseptic, followed by complete volatilization of the antiseptic, increases the crop 30 per cent. Plants grown under these conditions take very much larger amounts of nitrogen and other plant-foods from the treated soil. Further investigation and the discovery of additional facts led to the following suggested explanation of the results: All soils contain previously unsuspected groups of large organisms of the protozoa class, which feed upon living bacteria. When soil is sterilized by heat or by antiseptics, these protozoa are killed, while only part of the bacteria are destroyed. The bacteria remaining unharmed are now free to increase without hindrance by protozoa, and it is found as a matter of fact that they do increase with remarkable rapidity. For example, in a soil containing normally about seven million bacteria per gram, the number was reduced to about 400 by heating, but four days later they had risen to six millions, after which they increased to over forty millions per gram. It was found also that in the sterilized soils the ammonia had accumulated to an extent that would account for the increased yield of crop. The bacteria in the sterilized soil were chiefly of the class that change complex organic compounds into ammonia, while the absence of nitrifying bacteria, which had been largely destroyed by sterilization, made possible the accumulation of ammonia. According to this theory, the conversion of organic nitrogen into ammonia, depends upon the number of bacteria that produce this change, which, in turn, depends upon the extent to which the larger organisms, the protozoa, prey upon the ammonifying bacteria. This theory is in harmony with the beneficial results that

are observed in forcing-house practice when the soil is well baked after having become unsatisfactory through continued use. These facts are full of interest and are suggestive of possibilities along lines not heretofore appreciated.

PART II

Sources and Composition of Materials Used as Fertilizers

CHAPTER XIII

CLASSIFICATION AND DEFINITION OF PLANT-FOOD MATERIALS

The terms employed to describe and classify fertilizers and fertilizing materials are, in general, used loosely and without discrimination. For example, we find the words "fertilizer" and "phosphate," used with the same meaning. Many use the terms "fertilizer" and "manure" with different meanings, restricting the former to commercial plant-food materials and applying the latter exclusively to farm manure. By many the expressions, "plant-food" and "fertilizer" are always used as synonymous. It is desirable that the use of these terms should be reduced to some kind of system and definiteness. We shall attempt to define them as clearly and sharply as possible in accordance with what we regard as the best usage.

A fertilizer *is any substance, which, added to a soil, will, under favorable conditions, produce a better growth of crops, whether through direct or indirect action on the crop or on the properties of the soil.*

By reference to the definition of a plant-food (p. 6), it will be seen that the terms, plant-food and fertilizer, do not necessarily mean the same. Thus, all fertilizers are not plant-foods; indirect fertilizers which are added to soils to modify physical or chemical conditions are not necessarily plant-foods; for example, a large part of the material we add to soils in farm manures and green-crop manure is not used as plant-food at all, but it is useful in supplying the soil with organic matter which performs important functions, as we have seen (pp. 117-144).

The materials which come under the head of fertilizers

are numerous in kind, and different in source, in forms and in the manner in which they act.

CLASSIFICATION OF FERTILIZING MATERIALS

It is impossible to arrange materials used as fertilizers in sharply divided classes. In any system that can be

TABLE 22—CLASSIFICATION OF FERTILIZING MATERIALS

FERTILIZING MATERIALS (Fertilizers, manures, etc.)	I. Direct or nutritive	(A) Farm-produced	(1) Animal	(a) Excrements (b) Refuse (bones, carcasses, etc.)
			(2) Vegetable	(a) Straw, chaff, leaves, stalks, etc. (b) Kitchen wastes (c) Green crops (d) Muck, peat, etc.
			(3) Mineral	(a) Ashes (b) Deposits of marl, limestone, etc.
		(B) Commercial (artificial, prepared, manufactured, chemical, etc.)	(1) Animal	(a) Packing-house by-products (b) Stockyard refuse (excrements) (c) Refuse from fish-oil factories markets, etc.
			(2) Vegetable	(a) By-products of oil-mills (b) Tobacco waste, malt-sprouts, etc.
			(3) Mineral	(a) Nitrogen compounds (nitrates, ammonia, etc.) (b) Phosphorus compounds (phosphates) (c) Potassium compounds (potash salts)
	II. Indirect (stimulant, amendments, etc.)		(1) Mineral	(a) Calcium or lime compounds (b) Salt (c) Iron compounds
			(2) Vegetable	(a) Green crops (b) Waste materials (c) Lampblack, charcoal, soot, etc.

devised there are unavoidably cases where some materials belong to more than one division. The tabulated classification, on the opposite page, while not free from this objection, and also otherwise imperfect, will be found helpful in giving a fairly clear, general idea of the number and relations of the different terms used in speaking of fertilizers and, at the same time, it furnishes in outline a suggestive though incomplete statement of the general sources of fertilizing materials. Some of the substances mentioned are of theoretical rather than practical interest.

A direct or nutritive fertilizer *is one containing essential plant-food elements that are available (p. 7) at once or easily become so under favorable soil conditions.* The plant-food materials are in such forms or compounds that they can be immediately absorbed and used by plants, or else come into such forms in time to be used by crops during the growing season. Direct fertilizers dissolve easily in soil water at once, or readily change in the soil under ordinary conditions into such soluble form, and are therefore in condition to be taken up by plants either immediately or within a short time. For example, dried blood contains organic nitrogen in an insoluble form, which plants cannot use, but, under normal soil conditions, this insoluble nitrogen undergoes bacterial decomposition, ammonification and nitrification, sooner or later appearing in the quickly available form of nitrate nitrogen (p. 204).

An indirect or stimulant fertilizer (known also as a *soil amendment) is one which favorably influences plant growth, not by furnishing any needed element of plant-food, but chiefly by producing in the soil some effect beneficial to plant growth.* Among such beneficial effects are: (1) The conversion of unavailable into available plant-food in the soil, such as the conversion of insoluble into soluble potassium compounds by calcium (lime) car-

EXPERIMENT FIELDS. NEBRASKA STATION.

bonate; (2) changing the physical conditions of the soil so that favorable factors of structure (p. 101) are substituted for unfavorable ones, as illustrated by the flocculation (p. 104) of puddled clay by calcium compounds; (3) neutralizing acids and other substances in soils poisonous to plants (p. 128).

Indirect fertilizers may not be plant-foods at all, that is, may not contain any essential element used in plant growth, or they may contain essential plant-food elements that are already in the soil in sufficiently large amounts to supply the needs of crops indefinitely. For example, common salt (sodium chloride), when used, is scarcely ever applied because crops are in actual need of sodium or chlorine. The various forms of lime, calcium oxide (quicklime), calcium hydroxide (slaked lime), the sulphate and carbonate, are usually applied, not because soils contain an insufficient amount to furnish crops the calcium needed, but for the purpose of making neutral or preventing soil acidity, making insoluble potassium and phosphorus compounds available, and performing other functions beneficial to crop growth. In a similar way, the beneficial effects of green-crop manures often come much more largely from their influence upon the mechanical and chemical factors of the soil, making conditions more favorable for plant growth, than upon the amounts of nitrogen, potassium and phosphorus compounds they supply.

Farm-produced fertilizers include all materials commonly obtained on farms. They include (1) solid and liquid excrements of farm animals, (2) materials used for bedding, (3) unused portions of crops, including crop residues left in the soil, (4) all kinds of animal and vegetable waste, such as kitchen garbage, carcasses of animals, bones, human excrements, etc., (5) green-crop manures, (6) ashes, (7) muck and marl (found on many farms).

Commercial fertilizers are preparations or mixtures of plant-food materials, commonly sold under special trade-names. They are also known as *artificial, prepared* or *manufactured.* When they consist only of inorganic materials, they are known as *chemical* fertilizers or manures. The term "chemicals" is often applied to such materials as sodium nitrate, ammonium sulphate, salts of potassium, etc.

The materials used in making commercial fertilizers include substances found in, or prepared from, natural deposits, and, in addition, materials that form by-products of numerous industries, obtainable only through the channels of trade. While commercial fertilizers usually contain numerous constituent elements, their chief value depends on the presence of only three forms of plant-food, *nitrogen, phosphorus* and *potassium* compounds. Their agricultural value varies in accordance with the forms and amounts of these different plant-food compounds. Commercial fertilizers are known as *complete* and *incomplete.*

Complete fertilizers, called often *general* fertilizers, are those containing the three plant-food constituents, nitrogen, phosphorus and potassium compounds.

Incomplete fertilizers, known often as *special* fertilizers, are those containing only one or two of the three important plant-food constituents.

Plan of treatment.—In the remaining chapters of Part II, we shall discuss the sources and general character of the materials used as fertilizers, considering them in the following order:

(1) Commercial fertilizing materials containing compounds of
  (a) Nitrogen,
  (b) Phosphorus,
  (c) Potassium.

(2) Farm-produced fertilizing materials
 (a) Farm manure,
 (b) Green-crop manure.
(3) Indirect fertilizers:
 (a) Calcium or lime compounds,
 (b) Miscellaneous materials.

It is our purpose, in considering commercial fertilizing materials, to discuss in the chapters immediately following the source, character, methods of manufacture, composition and other similar points of general interest for each material, while we reserve for discussion in Parts III and IV points of more direct, practical interest, such as plant-food availability, advantages and disadvantages of use in fertilizing crops, cost of plant-food constituents, specific methods of use, etc.

In treating the subjects of farm manure, green-crop manure and indirect fertilizers, it has seemed better to consider the practical applications along with the more general features of interest instead of postponing it to later chapters.

CHAPTER XIV

NITROGEN-CONTAINING MATERIALS

The general character and relations of the nitrogen-containing materials used as fertilizers will be considered in the order indicated by the following outline:

1. **Inorganic or mineral compounds**: (1) Sodium nitrate, (2) ammonium sulphate, (3) potassium nitrate, (4) calcium cyanamid (lime-nitrogen), (5) calcium nitrate (lime-nitrate), (6) ammonium nitrate.

2. **Vegetable materials**: (1) Cottonseed-meal, (2) castor-bean pomace, (3) linseed-meal, (4) tobacco waste.

3. **Animal materials**: (1) Dried blood, (2) dried meat, (3) tankage, (4) dried fish, (5) hoof-meal, (6) horn-dust, (7) garbage-tankage, (8) commercial dried manures or excrements, (9) nitrogenous guanos, (10) hair, (11) leather-meal, (12) wool-waste.

INORGANIC OR MINERAL COMPOUNDS OF NITROGEN

The materials in this class came until recently, for the most part, from natural deposits and, in small part, from by-products of some manufacturing operations. At the present time they are, and will continue to be in increasing amounts, the direct products of manufacture.

Sodium nitrate (nitrate of soda), $NaNO_3$ (p. 40), commonly called *Chili saltpeter*, contains, when chemically pure, 16.47 per cent. of nitrogen. The commercial product used in fertilizers is about 95 per cent. pure and therefore contains about 15.65 per cent. of nitrogen. Samples found in the market generally contain considerably over 15 per cent. of nitrogen, but one occasionally contains

less than 15 per cent., owing usually to absorption of moisture (p. 41) or sometimes to mixture with other material.

Our source of supply is Chili, where immense beds occur, in which the sodium nitrate, in proportions varying from 17 to 60 per cent. (about equal to 3 to 10 per cent. of nitrogen), is mixed with other materials, such as gypsum, salt, sulphates of magnesium, potassium and sodium. The mixed nitrate is found in layers at 2 to 10 feet below the surface. The nitrate is purified and concentrated by dissolving and crystallization, after which the product is drained, dried and put up in bags holding 200 pounds. In this form, in which it usually reaches the consumer, the nitrate is a somewhat coarse powder, crystalline, varying in color from grayish white to pink and slightly brownish shades. This commercial product, as stated above, contains about 95 per cent. of pure sodium nitrate, the rest consisting mainly of moisture and common salt, with small amounts of sulphates of calcium, magnesium and sodium.

The present annual output of sodium nitrate is about 2,500,000 tons, containing nearly 400,000 tons of nitrogen. Much of this is used in manufactures and only a part for agriculture. The amount of nitrogen in the entire annual output of the nitrate of Chili is only about one-fifth of the amount of nitrogen used by the grain in one wheat and corn crop in the United States; but only about one-fourth (640,000 tons in 1910) of the total output of nitrate comes to the United States, and only a part of this is used in fertilizers.

Various estimates have been made as to when the Chili nitrate beds will become exhausted. In 1888, the Peruvian government estimated that the supply would last until 1913; in 1900, exhaustion was postponed by official estimate to 1940, and again in 1907 to 2032.

Deposits of sodium nitrate are known to exist in Cali-

fornia and Texas and also in Upper Egypt, but contain such large proportions of impurities that the nitrate cannot be obtained profitably.

The price of sodium nitrate varies considerably, retailing in recent years as high as $60 a ton and as low as $40, which is about equivalent, respectively, to 19 to 13 cents for one pound of nitrogen.

For special information regarding the use of nitrate of soda as a fertilizer in the growing of crops, see Parts III and IV (pp. 395-710).

Ammonium sulphate (sulphate of ammonia), $(NH_4)_2SO_4$ (p. 41), contains, when pure, 21.2 per cent. of nitrogen (equal to 25.75 per cent. of ammonia, NH_3). The commercial product used in fertilizers contains about 20 per cent. of nitrogen (equal to 24.3 per cent. of ammonia).

Ammonium sulphate is produced as a by-product in the manufacture of illuminating gas and coke. In the past, large amounts of ammonia have been allowed to go to waste, especially in the manufacture of coke, but the present tendency is to save it, though it is estimated that not more than one-fifth is saved in the United States at present. Generally speaking, one ton of coal produces from 8 to 25 pounds of ammonium sulphate, which contains 1.6 to 5 pounds of nitrogen. The amount now produced in the United States is in excess of 100,000 tons a year, while nearly as much more is imported, but only a small part of this is usually available for agricultural use.

Some years ago experiments were made in obtaining ammonia from the garbage of large cities, and considerable hope was felt that ammonia might be cheaply produced in abundance, but the process has not yet been successful.

During the past 10 years the price of ammonium sulphate has varied between $55 and $66, equivalent to 14 to 16½ cents per pound of nitrogen.

For information regarding the use of ammonium sulphate in its practical relations to the feeding of crops, see Parts III and IV (pp. 395-710).

Nitrogen compounds from atmospheric nitrogen.—It has been recognized for some time that in the future we must come more and more to depend for the nitrogen compounds required for commercial fertilizers upon chemical processes of utilizing the inexhaustible supply of nitrogen contained in the air (p. 38). Some years ago definite attempts were made to devise a chemical method for the commercial preparation of nitrogen compounds with the use of atmospheric nitrogen, but the technical processes actually in use have developed within the past 10 or 12 years. Two different nitrogen compounds are now being commercially manufactured, in which the nitrogen is obtained from the air. These two substances are known as calcium cyanamid (lime-nitrogen) and calcium nitrate (lime-nitrate). We will briefly consider these compounds here with reference to their mode of preparation and their composition. Their usefulness as fertilizers will be considered in another chapter (p. 427).

Calcium cyanamid ($CaCN_2$), when chemically pure, contains 35 per cent. of nitrogen; but the commercial product, known as *lime-nitrogen*, is not pure, and its percentage of nitrogen has varied from below 10 to over 16. The commercial product is a fine powder of dark-gray color, the particles being light in weight.

The two principal materials used in the preparation of lime-nitrogen are calcium carbide (the substance that is so familiar in the production of acetylene gas) and pure nitrogen obtained by liquefaction of air and distillation. The carbide, in the condition of a fine powder, is placed in a heated retort, into which the nitrogen is passed. The lime-nitrogen produced is removed from the retort in the form of a hard cake, which is cooled out of contact

with the air, then crushed to a powder and exposed to the air before packing. The chemical change taking place in the manufacturing operation may be represented as follows:

$$\underset{\substack{\text{Calcium}\\ \text{carbide}}}{\overset{64}{CaC_2}} + \overset{28}{2N} = \underset{\substack{\text{Calcium}\\ \text{cyanamid}}}{\overset{80}{CaCN_2}} + \underset{\text{Carbon}}{\overset{12}{C}}$$

According to this theoretical reaction, 64 pounds of calcium carbide combine with 28 pounds of nitrogen to produce 80 pounds of calcium cyanamid mixed with 12 pounds of carbon, in which case the mixed product would contain about 30 per cent. of combined nitrogen. These results are not realized in actual commercial operations, because the combination of nitrogen and carbide is not complete and because calcium carbide contains impurities present in the lime used in making the carbide, and these are found in the lime-nitrogen mixed with calcium cyanamid and carbon. The impurities in lime-nitrogen consist in large part of calcium oxide (quicklime) and compounds of iron, silicon, etc., in addition to the carbon formed in the operation, the presence of which is the cause of the dark color of the lime-nitrogen mixture. For these reasons, lime-nitrogen contains much less than the theoretical amount of nitrogen, only about 15 per cent. of the mixture instead of 30 per cent., as called for by the theoretical chemical reaction.

Lime-nitrogen is manufactured in several places in Europe. In America one plant, under the name of the "American Cyanamid Company," is in successful operation near Niagara Falls, New York, which made its first shipment in December, 1909. The product from the Niagara factory is all shipped to Baltimore, where there is a plant which further manipulates the product previous to distribution. One form in which lime-nitrogen has been put on the market is a mixture called "complete

ammonia drier," containing two-thirds of its nitrogen in the form of calcium cyanamid, one-sixth each in the form of nitrate and organic nitrogen, 50 per cent. of the mixture being organic matter. Another mixture contains 15 to 16 per cent. of nitrogen, of which 80 per cent. is cyanamid nitrogen and 20 per cent. ammonia nitrogen. These materials are in fine mechanical condition and ready for mixing with other materials. Cyanamid preparations are used to a considerable extent by manufacturers of complete fertilizers.

When lime-nitrogen is applied to soils, its nitrogen is not directly used as cyanamid nitrogen, but the compound undergoes gradual change in the presence of soil moisture, forming ammonia and calcium carbonate, as follows:

$$\underset{\substack{\text{Calcium}\\ \text{cyanamid}}}{\overset{80}{CaCN_2}} + \underset{\text{Water}}{\overset{54}{3H_2O}} = \underset{\substack{\text{Calcium}\\ \text{carbonate}}}{\overset{100}{CaCO_3}} + \underset{\text{Ammonia}}{\overset{34}{2NH_3}}$$

According to this reaction, the calcium cyanamid in 100 pounds of lime-nitrogen, containing 10 per cent. (equal to 3.5 pounds) of calcium cyanamid, would, in round numbers, combine with 2.35 pounds of water to furnish 1.5 pounds of ammonia (containing 1.25 pounds of nitrogen) and 4.35 pounds of calcium carbonate.

The estimated first cost of producing calcium cyanamid is, so far as data are available, about 10 cents for each pound of nitrogen. Its cost by the time it reaches the farmer is about the same as for other valuable forms of plant-food nitrogen.

For information regarding the advantages and disadvantages of lime-nitrogen as a fertilizer, see Chapter XXIII (p. 429).

Calcium nitrate ($Ca(NO_3)_2$), in the commercial form known usually as *lime-nitrate,* is another compound prepared by the use of atmospheric nitrogen, which has

recently come into agricultural use, especially in Europe. This material is a mixture of calcium nitrate and other substances and is known also under various other names, such as nitrate of lime, basic calcium nitrate, basic lime-nitrate, basic nitrate, lime-niter, lime-saltpeter, etc. It is essentially a mixture of calcium nitrate and lime. The calcium nitrate contained in this mixture is closely related to sodium nitrate ($NaNO_3$), the element calcium being combined with nitric acid in place of

LIME NITRATE FACTORY NEAR INNSBRUCK, AUSTRIA. AMERICAN FERTILIZER.

sodium. Strictly pure calcium nitrate contains 17.07 per cent. of nitrogen as compared with 16.47 per cent. in pure sodium nitrate. However, the commercial lime-nitrate contains only about 12 to 14 per cent. of nitrogen.

While there are in operation in Europe (in Norway, Austria and France) at least three different processes of making lime-nitrate, they are all based on the same general principle, differing only in some of the mechanical

details. Briefly stated, the general process consists of the following steps: (1) Ordinary air is passed through a powerful electric arc or flame, resulting in the combination of more or less of the oxygen and nitrogen in the form of nitric oxide (NO). (2) This nitric oxide, on exposure to air, combines with more oxygen to form nitrogen dioxide (NO_2). (3) By treatment with water, this last oxide is converted into dilute nitric acid (HNO_3), though there are some intermediate steps, which need not be considered here, before all of the NO_2 is converted into HNO_3. (4) The last step is to concentrate the nitric acid and treat it with calcium oxide (lime) and carbonate, forming calcium nitrate. Calcium nitrate attracts moisture rapidly and dissolves. To prevent this, two methods are employed. In one lime is added to a hot solution of calcium nitrate and after cooling, it is broken up and passed through a sieve. This is basic lime nitrate and contains 9 or 10 per cent. of nitrogen. The other method of putting up the product is to melt the concentrated nitrate and either pour it into receptacles and allow it to solidify by cooling, or, after cooling, grind it fine and put in air-tight packages. This latter product contains 12 to 14 per cent. of nitrogen.

Nitrogen in lime-nitrate is estimated to cost about 15 cents a pound near the manufactory. Little of the European product has yet been brought to America. It has been stated recently that the first plant is being established in the United States for the manufacture of lime-nitrate, being located at Great Falls, South Carolina. It is expected to be in active operation sometime during 1911.

For information regarding the usefulness of lime-nitrate as a fertilizer, see Chapter XXIII (p. 427).

Ammonium nitrate (NH_4NO_3, p. 41) is not at present an available compound for common use in fertilizers on account of its high cost. It is, however, a compound of

much interest on account of certain marked advantages that it offers as a fertilizing material. Nitrate of soda, lime-nitrate and lime-nitrogen have the disadvantage of bulk. For each pound of nitrogen, transportation must be paid on 6 to 10 pounds of cheap material. Ammonium nitrate is a compound rich in available nitrogen, furnishing probably the most concentrated form of plant-food nitrogen that we have. When pure, it contains 35 per cent. of nitrogen, one-half in the form of nitrate and one-half in the form of ammonia. A high-grade commercial product containing 30 to 33 per cent. of nitrogen would reduce the cost of nitrogen transportation at least one-half, as compared with nitrate of soda, and two-thirds in comparison with low-grade cyanamid and calcium-nitrate. The solution of cheap production of ammonium nitrate must be found in the economical production of ammonia and nitric acid in the same factory. The cheap production of nitric acid has apparently been accomplished already and the main part of the problem now lies in the cheap production of ammonia. Some hope is held out in this direction by recent reports from Germany of successful laboratory experiments in which ammonia is produced synthetically by compression of hydrogen and nitrogen at high temperature in the presence of finely powdered uranium oxide, or of pure iron.

Potassium nitrate (KNO_3, p. 41), known commonly as nitrate of potash, niter and saltpeter, is an extremely valuable form of plant-food for nitrogen as well as potassium, but it is too expensive for common use in fertilizers on account of the demands for various manufacturing purposes and especially gunpowder. It comes into market as a fertilizer in small amounts in a form containing 13 per cent. of nitrogen and 36.5 per cent. of potassium (equal to 44 per cent. of potash), while pure potassium nitrate contains 13.85 per cent. of nitrogen and 38.7 per

cent. of potassium (equal to 46.6 per cent. of potash). It occurs in small amounts in very impure form as waste from gunpowder factories.

VEGETABLE NITROGENOUS MATERIALS

The materials in this class are the seed residues obtained in oil factories and are limited in amount by the yield of the crops from which the seed comes.

Cottonseed-meal is the product formed when oil is removed from cottonseed, after which the extracted residue is ground fine. The annual yield of cottonseed in the United States is about six million tons, most of which is used for production of oil and meal. Cottonseed-meal has been extensively used as a fertilizer, especially in the South. When of good quality, it contains about 7 per cent. of nitrogen along with 1.3 per cent. of phosphorus (equal to 3 per cent. of phosphoric acid) and 1.65 per cent. of potassium (equal to 2 per cent. of potash). When mixed with cottonseed-hulls, these percentages are lower. In addition to its plant-food constituents, cottonseed-meal is valuable in fertilizers, because when used in sufficient quantity it produces a desirable mechanical effect in a mixed fertilizer, absorbing moisture, preventing caking and insuring a loose condition of particles. Cottonseed-meal is highly valued as a food for cattle and, when thus used, a large proportion of the plant-food constituents is recovered in the manure, which makes this the most economical way of utilizing it as a fertilizer. When applied directly to the soil, it is a valuable fertilizer, but cannot be generally used in this way profitably when it costs over $25 a ton.

Castor-bean pomace is a by-product of castor-oil factories. Its chief use is for fertilizing purposes. It is generally less rich in plant-food constituents than cottonseed-meal, containing about 5.5 per cent. of nitrogen,

along with 0.9 per cent. of phosphorus (equal to 2 per cent. of phosphoric acid) and 0.8 per cent. of potassium (equal to 1 per cent. of potash).

Linseed-meal is the residue left after extracting oil from flaxseed. Its extensive use as cattle-food makes it too high-priced for common use as a source of nitrogen in commercial fertilizers. It contains about 5.5 per cent. of nitrogen, together with nearly 0.9 per cent. of phosphorus (equal to 2 per cent. of phosphoric acid) and 1.25 per cent. of potassium (equal to 1.5 per cent. of potash).

Tobacco Waste.—See p. 284.

ANIMAL NITROGENOUS MATERIALS

The materials in this class come, for the most part, from the meat-packing industries; they are animal by-products more or less rich in nitrogen and are known in general terms as blood, tankage and offal. In the United States most of the nitrogen used in commercial fertilizers has come from this source. It is estimated that more than a million tons of these products are annually disposed of by packing-house companies.

Dried blood used in fertilizers is prepared for market by evaporating, drying and grinding. The color varies from red to black according to the temperature and method employed in drying. Red dried blood is of higher grade than black, containing more nitrogen, being more uniform in composition and having only a small amount of phosphorus compounds. It usually contains 13 to 15 per cent. of nitrogen. Black dried blood is often mixed with hair, dirt and various kinds of animal refuse and therefore varies greatly in composition, the percentage of nitrogen ranging from 6 to 12. It also contains more or less phosphorus, sometimes as much as 1.30 to 1.75 per cent. (equal to 3 to 4 per cent. of phosphoric acid). Black dried blood is somewhat tough or leather-like in texture

and decays in the soil less rapidly than the red. It is the black dried blood that is most extensively used in fertilizers.

Dried meat is known under different trade-names, such as animal matter, ammonite, azotin, meat-meal, etc. It consists of the dried, ground, inedible soft portions of animal carcasses, such as tendons, membranes and other portions of meat, from which fat has been extracted, and also of by-products from beef-extract manufacture. It comes mainly from slaughter-houses and rendering-plants. It varies considerably in composition; it usually contains 10 per cent. of nitrogen and often as much as 13 or 14 per cent. It also usually contains 1.30 to 1.75 per cent. of phosphorus (equal to 3 to 4 per cent. of phosphoric acid).

Tankage consists of a mixture of miscellaneous slaughter-house refuse that is unavailable for other commercial purposes, such as bone, flesh, tendons, intestines, lungs, blood, hair, hides, horns, hoofs, etc. The mixed materials are cooked in tanks under pressure to remove fat, after which they are dried and ground. Tankage varies greatly in composition because the proportions of different materials used vary greatly. When bone materials are in excess, it is usually called bone-tankage; and when the softer, more highly nitrogenous materials predominate, it is often called meat-tankage. In the case of small slaughter-houses, the tankage varies much more in every way than that prepared by large packing-houses and rendering-plants.

We recognize two general varieties of tankage, nitrogenous or concentrated tankage and crushed or mixed tankage. In the first kind, the waste water or liquor that results from the cooking of bones and meat refuse is evaporated and makes a product high in nitrogen, often over 12 per cent., but with little phosphorus. This product, which by itself is usually sticky and diffi-

cult to handle, may be ground and mixed with dry, inert materials to give it a good mechanical texture, or it may be used in mixing with ordinary tankage to increase its percentage of nitrogen. In mixed or crushed tankage, the composition varies greatly, the nitrogen ranging from 4 to 9 per cent. and the phosphorus from 1.3 to 5.3 per cent. (equal to 3 to 12 per cent. of phosphoric acid). Two forms of tankage often quoted in price lists of fertilizing materials are the following: (1) 4 per cent. of nitrogen and 7.5 of phosphorus (equal to 17 of phosphoric acid), and (2) 6.5 per cent. of nitrogen and 4 of phosphorus (equal to 9 of phosphoric acid). Owing to the extreme variations in composition, tankage should be bought only on a guarantee of nitrogen and phosphorus (or phosphoric acid).

Dried ground fish and acidulated fish.—Dried fish, fish-scraps and ground fish, sometimes called fish-guano, consist of by-products coming mainly from fish-oil works, fish-canning factories, fish-salting plants, etc. In the United States, menhaden constitute the main source of fish-scrap. The material obtained from the manufacture of fish-oil is the residue left after extracting the oil, a process which removes from the fish little that is of value as a fertilizer. The fresh fish are cooked by steam, then pressed to remove the oil, and dried either in the air or by steam, after which the mass is ground. The scrap is sometimes sprinkled with dilute sulphuric acid (oil of vitriol) by which putrefaction is checked and the bones softened and to some extent dissolved. Dried fish is quite uniform in composition, containing 6 to 9 per cent. of nitrogen and 2.25 to 4 per cent. of phosphorus (equal to 5 to 9 per cent. of phosphoric acid). The product coming from canning-works consists more largely of skin, bones, etc., and is therefore more variable in composition, containing usually more phosphorus and less nitrogen. Acidulated dry fish usually contains slightly

smaller percentages of nitrogen and phosphorus than the untreated fish. The source of eastern supply has been largely from the Atlantic Ocean, Lake Erie, etc. Raw fish and refuse are sometimes applied as such to the soil as fertilizer by those living near the source of supply. The menhaden industry along the Atlantic coast engages about 30 factories, the average annual output of fertilizer scrap amounting to about 70,000 tons.

Hoof-meal and horn-dust are by-products of slaughter-houses; they contain 10 to 15 per cent. of nitrogen and about 0.9 per cent. of phosphorus (equal to 2 per cent. of phosphoric acid). These materials are sometimes treated by superheated steam or with dilute sulphuric acid and the nitrogen is rendered more available as plant-food.

Garbage-tankage is material obtained by drying city garbage, which consists of mixed animal and vegetable refuse. Sometimes it is prepared for use as fertilizer by charring, but usually the grease is extracted and the residue dried and ground. Its composition varies greatly. From 15 to 30 per cent. of the garbage collected is available as marketable tankage. In some cases the tankage is treated with dilute sulphuric acid and then mixed with calcium phosphate and potash salts to produce a complete commercial fertilizer. Garbage-tankage may contain 2.5 to 3 per cent. of nitrogen, 0.65 to 1.30 per cent. of phosphorus (equal to 1.5 to 3 per cent. of phosphoric acid) and 0.6 to 1.25 per cent. of potassium (equal to 0.7 to 1.5 per cent. of potash). This material is regarded as low-grade plant-food. In both composition and availability, its value is variable. It should be purchased only on a guarantee of composition.

Commercial manures from animal excrements.—During the past few years there have come into the market quite large quantities of dried and ground animal excrements. These consist largely of manure obtained at

stock-yards, with some admixture of dirt and refuse. Those most commonly sold are cattle, pig and sheep manure, the last being more common. The phosphoric acid is largely available. The following analyses show about how these materials run in composition, the average and variations being given in case of sheep and pig manures:

TABLE 23—COMPOSITION OF COMMERCIAL PULVERIZED ANIMAL MANURES

	Pulverized sheep manure		Pig manure		Cattle manure
					Per cent
Nitrogen	2.50 Per cent.	(1.51 to 3.09)	1.75 Per cent.	(1.61 to 2.03)	1.34
Phosphorus	0.65	(0.40 to 1.10)	0.75	(0.55 to 1.00)	0.40
(Equal to phosphoric acid)	1.50	(0.95 to 2.50)	1.75	(1.30 to 2.30)	0.90
Potassium	1.25	(0.30 to 1.85)	0.85	(0.85 to 1.00)	0.70
(Equal to potash)	1.50	(0.33 to 2.24)	1.00	(1.00 to 1.20)	0.85

Nitrogenous guanos are formed in warm, dry regions from the excrements of birds, which are mixed with the bodies of dead birds, fragments of fish, feathers, seaweed, etc. The birds live largely on fish and the resulting excrements are rich in nitrogen. When these deposits occur in warm, rainless regions, they are high in nitrogen, containing 7 per cent. or more, and as much as 20 per cent. has been reported in old deposits. The nitrogen in old guano is mainly in the form of ammonia compounds. Peruvian guano, which was once used very extensively and which was deposited on groups of islands off the coast of Peru, is practically exhausted. Most of the material that now comes into market consists of comparatively fresh deposits and relatively little is used in this country. Fresh deposits are being made at the rate of 10,000 tons a year, it has been estimated. Fresh guano is light gray in color; it may in extreme cases contain as high as 16 per cent. of nitrogen and 4

per cent. of phosphorus (equal to 9 per cent. of phosphoric acid). In time the color changes to brown as the material undergoes decomposition. Most of what now comes into market is a loose, dry powder and contains 5 to 8 per cent. of nitrogen; it often smells of ammonia. Some nitrogenous guano is found on Ichabod Island and in Damaraland on the southwest coast of Africa, which is less rich in nitrogen than that of Peru. In some cases, low-grade guano is treated with ammonium sulphate or some other nitrogen compound in order to make it pass for a rich guano. "Dissolved" Peruvian guano has been treated with dilute sulphuric acid to change its ammonia into sulphate and dissolve the phosphoric acid compounds. *Bat* guano is found in caves in America and Africa but is insufficient in amount to be of any commercial importance. In general, the guanos are of greater historical interest than of present or future importance as a source of plant-food.

Hair and leather.—Hair is often found mixed with dried blood and tankage. It is rich in nitrogen, containing about 15 per cent. It decomposes with extreme slowness and may be regarded as practically useless for the feeding of crops. The same is true of fur-waste and feathers.

Leather in the form of scraps and ground leather is a waste product of various industries. When treated with superheated steam and then dried or partially roasted, the material can be ground fine and is then called *leather-meal*. Roasted leather, finely ground, has been used to adulterate dried blood, which it resembles in color. Leather contains 7 to 8 per cent. of nitrogen. It undergoes decomposition in soils with extreme slowness (p. 432).

Hair and leather materials contain nitrogen in a form which obstinately resists the action of micro-organisms and which therefore is practically unavailable as plant-

food during the growing season of a crop. By proper treatment with sulphuric acid, the nitrogen of these and similar materials can be changed into forms more readily available, but the cost of such treatment appears, in view of present prices of nitrogen, to make it impracticable.

Wool-waste consists of by-products of such industries as carpet-making, manufacture of woolen cloth, etc. Pure wool contains about 15 per cent. of nitrogen, but wool-waste usually is mixed with so much cotton that the percentage of nitrogen may be reduced as low as 5. The nitrogen in wool-waste is not quickly available plant-food. While treatment with sulphuric acid can make the nitrogen available, it is too costly to be practicable.

CHAPTER XV

PHOSPHORUS-CONTAINING MATERIALS

The materials that furnish the phosphorus compounds used in fertilizers are, for the most part, phosphates of calcium (lime); for a description of their chemical composition, the meaning of different names, etc., see pages 42-49. Most of the phosphates used in America come from two sources, (1) mineral phosphates and (2) bones of slaughtered animals, the latter furnishing, however, only a small proportion compared with the former. In addition, but in relatively small amounts, phosphorus compounds for fertilizing purposes are obtained from basic-slag phosphate, fish, phosphatic guanos, vegetable materials, etc. The manufactured product called *superphosphate* is the form which, whatever the source of the original material, is most extensively used in commercial fertilizers.

We will, for convenience, study the phosphorus-containing materials in accordance with the following outline:

1. *Mineral materials:* (1) Rock-phosphates, (2) apatite, (3) guano phosphates.

2. *Animal materials:* (1) Bones, raw and steamed, (2) bone-tankage, (3) bone-black, (4) bone-ash.

3. *Manufactured products:* (1) Superphosphate, or acid phosphate, (2) dissolved bone, (3) concentrated superphosphate, (4) basic-slag phosphate, (5) Wiborg and Wolter phosphates, (6) Palmaer phosphate.

MINERAL PHOSPHORUS-CONTAINING MATERIALS

By far the largest part of the phosphorus compounds used as fertilizers in feeding crops comes from the materials embraced in this class.

Rock-phosphates are commonly known as South Carolina, Florida, Tennessee rock or phosphate. Under these general terms we include those deposits which consist more or less largely of tri-calcium phosphate ($Ca_3(PO_4)_2$, p. 47). These are found in many different places, varying in form, condition and purity. They contain phosphorus varying in amount from below 9 to 18 per cent. or more (equal to 20 to 40 per cent. of phosphoric acid (P_2O_5), or to about 45 to 90 per cent. of tri-calcium phosphate); the usual proportions are between 11 and 15.5 per cent. of phosphorus (about equal to 25 and 35 per cent. of

EFFECT OF DIFFERENT FORMS OF PHOSPHORUS COMPOUNDS ON MILLET. NEW YORK STATE (GENEVA) STATION.

phosphoric acid, or 55 and 77 per cent. of tri-calcium phosphate). The materials mixed as impurities with rock-phosphate are usually sand, clay and limestone (calcium carbonate). Deposits of rock-phosphates occur extensively in Florida, South Carolina and Tennessee, which have been worked for periods varying from about 20 to more than 40 years. Deposits have been reported in Pennsylvania, New Jersey, New York, North Carolina, Arkansas, Kentucky, Nevada and California, but of these only the Arkansas field has become productive.

During the past five years immense deposits of unknown extent have been discovered in Utah, Wyoming and Idaho, which have not been developed yet. The lands containing these northwestern deposits have been kept under the control of the national government in order to prevent their wasteful exploitation by private interests. Undoubtedly numerous extensive phosphate fields remain yet to be discovered. Deposits occur in many other countries, but there is none yet known so extensive as those of the United States.

The mining of American phosphate rock began in South Carolina in 1868 and in Florida 20 years later, and in Tennessee in 1892. Since 1867 the amount of rock-phosphate produced in this country has been about 35 million tons, valued at $140,000,000, much of which has been exported to Europe, which has for years absorbed practically all of the high-grade output of Florida. Something of the recent growth and extent of the industry can be realized from the fact that there was an increase in the production of phosphate rock from about one million tons (valued at $2,675,000) in 1897 to about 2,400,000 tons (valued at about $11,000,000) in 1909; nearly one-half of our output is exported, the exports of phosphate-rock amounting in 1909 to 1,020,000 tons, valued at $4,500,000.

Outside of the United States, the most extensive and important deposits of rock-phosphates are probably those of North Africa, which are rich in phosphorus compounds and with only small amounts of impurities. Numerous West Indian and Pacific Ocean islands contain deposits, but many of these have been practically exhausted. England France, Belgium and Germany also furnish some deposits, but they are usually of low grade. Extensive deposits have been recently reported in China.

There are many facts of general interest in regard to the composition, character, formation and extent of the different phosphate fields in the United States, but we can only touch

superficially upon a few of the more important. The rock-phosphate of South Carolina usually varies from 10 to 12.5 per cent. of phosphorus (equal to 23 to 28 per cent. of phosphoric acid, or 51 to 62 per cent. of tri-calcium phosphate); those of Florida, from below 9 to over 18 per cent. of phosphorus (equal to 20 to 40 per cent. of phosphoric acid or 45 to 90 per cent. of tri-calcium phosphate); those of Tennessee from below 9 to over 15 (equal to 20 to 35 per cent. of phosphoric acid, or 45 to 77 per cent. of tri-calcium phosphate), but much of it is near the higher amount. In both South Carolina and Florida, the material is found in beds varying in thickness from one foot to many feet. These deposits are often located in beds of rivers; the phosphate material is distributed through these beds in chunks varying in size from that of small pebbles to that of immense rocks weighing over a ton. The material, after being removed from its location, is usually washed free from the accompanying impurities, after which it is dried and ground fine. When ground so fine as to be dust-like, phosphate rock is called "*floats*." In many cases, especially in the river deposits, the material contains fossilized fragments of fish bones, shells, shark's teeth, etc. The Tennessee phosphate is found in masses in the form of veins and pockets. It is fairly free from iron and aluminum compounds (2 to 5 per cent.) but contains 10 to 14 per cent. of calcium carbonate; it can be ground without previous washing and drying. The South Carolina and Florida phosphates contain but little iron and aluminum compounds but considerable sand and calcium carbonate. The South Carolina land-phosphate contains some iron and aluminum compounds (2 to 4 per cent). The objectionable effect of iron and aluminum compounds in rock-phosphate upon the phosphate constituents of fertilizers will be considered under the subject of superphosphates (p. 273).

Apatite is a mineral containing calcium phosphate and, in addition, one of the elements, fluorine or chlorine. Pure

apatite contains about 17.5 per cent. of phosphorus (equal to 40 per cent. of phosphoric acid or 88 per cent. of tri-calcium phosphate). Apatite is a definite chemical compound and is probably the original source of phosphorus in all other phosphorus compounds. It is more widely distributed than any other form of phosphate. Its use in making fertilizers is limited because it is extremely hard and does not dissolve easily in acids. It is mined in a small way in Canada and Norway. Apatite, as taken from the ground, is mixed more or less with other substances present in the earth; it therefore varies in composition according to the amount of impurities, usually ranging from 14 to 18 per cent. of phosphorus (equal to 32 to 41 per cent. of phosphoric acid, or 70 to 90 per cent. of tri-calcium phosphate). Canadian apatite is usually high in phosphorus. Apatite is sometimes used in making special preparations, which will be noticed under manufactured products (p. 277).

Guano phosphates.—Guanos containing considerable percentages of phosphorus were for some years extensively used until the rock-phosphate largely displaced the trade. Small amounts still come into the market, mainly from the West Indies and from islands in various parts of the Pacific Ocean.

ANIMAL PHOSPHORUS-CONTAINING MATERIALS

In large packing-houses, all bones of any appreciable size are utilized for various commercial purposes, such as the manufacture of buttons, knife-handles, etc., and only the discarded fragments and small bones that cannot be otherwise utilized go into fertilizing material. Bones furnished to agriculture practically all of the phosphorus applied as fertilizer until the advent of the rock-phosphate.

Bones and bone products used for fertilizing purposes are known under such general names as *bone phosphate,*

animal phosphate, bone phosphate of lime, bone-tankage, bone-black, bone-ash, etc.

The materials, aside from water, of which bones consist can be divided into two kinds, inorganic and organic. The inorganic portion constitutes the hard framework, making up from 50 to 60 per cent. of the whole weight of raw bone (about 70 per cent. of dry bone), and consists largely of tri-calcium phosphate ($Ca_3(PO_4)_2$, p. 45) with small amounts of calcium and magnesium carbonate. The organic part of bones consists mainly of two substances: (1) A soft, flesh-like substance called *ossein* or *collagen,*

ACTION OF DIFFERENT PHOSPHATES ON CABBAGE. NEW YORK STATE (GENEVA) STATION.

distributed through the entire mass of the bone (forming 25 to 30 per cent. of the weight); this material is commonly known as *bone-cartilage* and is very rich in nitrogen. (2) The other organic substance is animal fat.

When a bone is allowed to lie in a dilute acid for some time, the inorganic framework (calcium phosphate) is completely dissolved, leaving the soft, cartilaginous organic matter still holding the original shape of the bone. The familiar substance, *gelatin,* is a direct product of the bone-cartilage, formed by boiling bones a long time. Gelatin by further

treatment can be converted into *glue*. When bones are burned, the fat and nitrogenous compounds are destroyed, and only the mineral portion remains.

The amount of phosphorus and nitrogen in bones varies with different conditions, such as kind of animal, age, location of bone, etc. For example, fish bones are much richer in nitrogen than beef bones. Bones of young animals contain more nitrogen and less phosphorus, as compared with older animals. The large, hard bones, the ones bearing greatest strain, are richer in phosphorus and less rich in nitrogen than the smaller, more compact bones. However, the differences that we find in the percentages of nitrogen and phosphorus in the bones used for fertilizing purposes are due more largely to differences in methods of treatment than to differences of composition in the original bones.

Raw bone includes any bone that has been ground in its natural state without previous treatment by steaming, boiling, etc. It is usually found in market under the names of bone-meal, raw bone-meal, coarse ground bone, etc. Raw bone contains the fat naturally present in bones, and its presence is objectionable for the following reasons: (1) The presence of fat makes it practically impossible to grind bone fine enough for use as a fertilizer. (2) The fat protects the particles of bones from bacterial action and makes decomposition in the soil much slower. (3) It is believed that some of the decomposition products of fat, when present in soils, are poisonous to plants. (4) The fat itself has no value as plant-food, but by its presence reduces the percentage of nitrogen and phosphorus in bone.

Raw bone of good commercial quality should contain 3.5 to 4.5 per cent. of nitrogen, and 9 to 11 per cent. of phosphorus (about equal to 20 to 25 per cent. of phosphoric acid, or to 45 to 55 per cent. of tri-calcium phosphate).

Steamed bone products include materials sold under various commercial names, such as bone-meal, fine bone-meal, pure ground bone, bone-flour, bone-dust, etc. The

various terms refer usually to fineness of division rather than to differences of composition. Fineness of bone affects its value as fertilizing material; the finer the particles, the more quickly do its plant-food constituents become available. Most of the bone products used for agricultural purposes have been treated by some process which removes the fat, to be used in soap-making, and usually more or less nitrogen for making gelatine or glue, according to the process employed. On account of the large demand for bones for various purposes and their consequent increase of value, there has been some temptation to adulterate bone products, both raw and steamed, with such substances as calcium carbonate, gypsum, coal-ashes, ground oyster-shells, ground rock-phosphate, etc.

Fat is removed from bones by boiling in water or by steaming under pressure. In some cases the fat is extracted by treatment with benzine, a process which has the advantage of removing little or no nitrogenous material, while treatment with boiling water or with steam takes out some of the nitrogen compounds. By treating the fat-free bones at a much higher temperature and pressure (50 or 60 pounds), the cartilaginous part of the bone is converted into gelatin, which dissolves in water and separates from the mineral portion of the bone. The removal of fat makes fine grinding much easier, and removal of part of the cartilage from the fat-free bone makes it possible to grind the remaining portion very fine. Steamed bone-meal or bone-flour generally has a somewhat gritty feeling and a characteristic odor.

The composition, as well as the fineness, of bone products is affected by the character of treatment they have been subjected to. Fat-free bone-meal contains, according to samples on the market, 1.8 to 3.5 per cent. of nitrogen and from 9.7 to 12.3 per cent. of phosphorus (about equal to 22 to 28 per cent. of phosphoric acid or 48 to 62 per cent. of tri-calcium phosphate). In case of bone treated for the

manufacture of gelatin or of glue, the nitrogen is often reduced below 2 per cent. and sometimes below 1 per cent., while the phosphorus may go as high as 12 or even 13 per cent. (about equal to 28 to 30 per cent. of phosphoric acid, or 62 to 66 per cent. of tri-calcium phosphate). The bone-dust of one particular glue-factory during a period of several years has varied, for example, from 1.16 to 1.74 per cent. of nitrogen and from 10.56 to 13.64 per cent. of phosphorus (equal to 24 to 31 per cent. of phosphoric acid, or 52.8 to 68.2 per cent. of tri-calcium phosphate). Bone-flour prepared from bone after the extraction of fat with benzine may contain as much as 6 per cent. of nitrogen. Some products appear on the market under the name of bone-meal, containing less than 2 per cent. of nitrogen and only 7 or 7.5 per cent. of phosphorus (equal to 16 to 17 per cent. of phosphoric acid, or 35 to 37 per cent. of tri-calcium phosphate). In view of the possibility of so great variations, it can be readily understood how important it is to purchase these materials only under definite guaranteed percentages of nitrogen and phosphorus. The degree of fineness should also be guaranteed.

Bone-tankage, while more or less rich in nitrogen, contains varying amounts of phosphorus, according to the relative proportions of bone and meat present. Tankage consisting almost entirely of bone is, of course, about like bone in composition. It also follows that in a genuine bone-tankage the higher the percentage of phosphorus, the lower is the percentage of nitrogen. The bone in tankage may be usually regarded as having the same agricultural value as boiled or steamed bone of the same degree of fineness. The materials of tankage are often found to be rather too coarse.

The phosphorus in tankage may vary all the way from 2.6 to 8.8 per cent. (about equal to 6 to 20 per cent. of phosphoric acid, or 13 to 44 per cent. of tri-calcium phosphate). Bone-tankage proper may be regarded as containing from

6.6 to 8.8 per cent. of phosphorus (equal to 15 to 20 per cent. of phosphoric acid, or 33 to 44 per cent. of tri-calcium phosphate). Tankage should never be purchased except on a guaranteed percentage of nitrogen and phosphorus. In illustration of the importance of purchasing only guaranteed material the following figures represent results of samples of tankage recently analyzed:

TABLE 24—VARIATION IN COMPOSITION OF TANKAGE

Per cent. of nitrogen	Per cent. of phosphorus,	Phosphoric acid (P_2O_5)	Tri-calcium phosphate ($Ca_3P_2O_8$)
9.7	2.64	6.0	13.2
6.5	4.10	9.3	20.5
6.5	5.50	12.5	27.5
6.0	5.70	12.9	28.5
5.5	7.50	17.0	37.5
5.0	7.90	18.0	39.5

Bone-black, known also as *animal charcoal* and *bone-charcoal,* is a product manufactured from bone, which finds its chief use in sugar-refineries. Bone-black is made by heating carefully selected bones in closed vessels, with exclusion of air. By this process, the fat, nitrogen and water are removed and the remaining mass consists mainly of tri-calcium phosphate and carbon. It is ground into a coarse, granular condition and thus becomes commercial bone-black. The presence of the carbon, coating the particles of phosphate, makes it slow to change to available plant-food, offering resistance to bacterial or other dissolving agents. When bone-black has been used repeatedly in sugar-refining, it becomes useless for the purpose and is sold as a fertilizer either for direct use or to be made into superphosphate, known as *dissolved bone-black.* Good bone-black may contain 13 per cent. or more of phosphorus (equal to 30 per cent. of phosphoric acid, or 66 per cent. of tri-calcium phosphate). At the present time bone-black forms only an insignificant part of the phosphorus used in fertilizers.

Bone-ash, as the name implies, is made simply by burning bones in open air. The nitrogen is, of course, wholly

lost, the remaining portion containing 13 to 15 per cent. of phosphorus (equal to 30 to 35 per cent. of phosphoric acid, or 66 to 77 per cent. of tri-calcium phosphate). It was formerly imported from Argentina but is now practically out of the market.

MANUFACTURED PRODUCTS

Superphosphate or acid phosphate.—Under this head we consider the products made by treating an insoluble phosphate with an acid and thereby changing it into a soluble phosphate. The process was first applied to bones, but at the present time rock-phosphate furnishes the material that is almost exclusively employed. The term, *superphosphate*, may be regarded as a general term applying to any soluble phosphate prepared by treatment with an acid, while the expression, *acid phosphate*, is applied more particularly to soluble phosphate made by treating rock-phosphate with sulphuric acid (oil of vitriol). In our American market quotations, the use of the word superphosphate has been almost, if not entirely, superseded by the expression, acid phosphate, while in England the latter term is rarely used.

In general, superphosphates may be defined as mixtures consisting chiefly of soluble or acid calcium phosphate ($CaH_4(PO_4)_2$, p. 47) and hydrated calcium sulphate (gypsum, p. 55) with small amounts of other constituents coming from the impurities in the original phosphate material.

With pure tri-calcium phosphate ($Ca_3(PO_4)_2$) 100 pounds would require about 63 pounds of pure sulphuric acid, and would produce about 75 pounds of soluble or acid calcium phosphate and 88 pounds of gypsum (calcium sulphate and water). Therefore, in 100 pounds of the completed superphosphate made from pure materials, there would be about 54 pounds of gypsum and 46 pounds of soluble calcium phosphate (equal to 12 per cent. of phosphorus or 28 per cent. of phosphoric acid). But we usually have a considerably larger proportion of calcium sulphate and a correspond-

ingly smaller proportion of soluble calcium phosphate, because the phosphate material usually contains some calcium carbonate or other constituents that reduce the proportion of soluble phosphate and increase that of gypsum in the completed product.

In making insoluble into soluble phosphate, it is seen, therefore, that the process is one of *dilution* so far as the percentage of phosphorus is concerned. Whatever the percentage of phosphorus in an insoluble phosphate, whether rock, bone, apatite, or other form, the percentage of phosphorus in the completed product is less than half what it was before dilution by treatment with sulphuric acid. (For the chemical reactions representing the action of sulphuric acid in the production of superphosphate, see page 46.)

In the manufacture of acid phosphate or other superphosphate, the material is very finely ground and mixed with sulphuric acid, diluted so as to contain about 60 per cent. of the pure acid. The mixed mass, more or less wet and hot, is allowed to stand for some time until the chemical changes are completed; the gypsum formed takes up the water and the whole mass solidifies, after which it is crushed fine and stored. In those phosphate materials in which the impurity is largely calcium carbonate, more acid is used and the product contains more gypsum and is therefore more dry and more easily powdered. In order to avoid the presence of free sulphuric acid in acid phosphate, somewhat less sulphuric acid is used than is actually required to dissolve the phosphate completely. Acid phosphate generally, therefore, contains some undissolved tri-calcium phosphate, which, on standing, reacts with the soluble phosphate and forms some reverted calcium phosphate (p. 48).

The amount of sulphuric acid that should be used depends upon the composition of the phosphate material. Excess of acid is to be avoided for three reasons: (1) It results in an undesirable, sticky, mechanical condition, (2) it is

disagreeable to handle, and (3) it is difficult to store in bags because the acid destroys them. Roughly, about one-half ton of sulphuric acid is used in making one ton of superphosphate. "Sludge" acid, which is obtained in large amounts from the refining of petroleum and which cannot be economically purified for repeated use, has been extensively used in making acid phosphate. This acid imparts to the product a characteristic odor. The claim has been made that acid phosphate made with "sludge" acid is injurious to plants owing to poisonous products contained in the acid. No evidence has been furnished to confirm such a statement.

The impurities in rock-phosphates that interfere most seriously with their conversion into satisfactory acid phosphate are compounds containing iron and aluminum. These compounds interfere with satisfactory results in two ways: (1) The resulting mixture has a jelly-like consistency, which is hard to handle or convert into a dry, fine powder. (2) The presence of iron or aluminum compounds tends to cause the formation of reverted phosphate (p. 47), in which the very insoluble iron and aluminum phosphates form an undesirably large proportion.

There are two well-recognized grades of acid phosphate in the market, one containing about 6 and the other 7 per cent. of phosphorus (equal to 14 and 16 per cent. of phosphoric acid). Some brands found in the market run as low as 4.8 and 5.3 per cent. of phosphorus (equal to 11 and 12 per cent. of phosphoric acid). Most samples contain about 6 per cent. of phosphorus (equal to 14 per cent. of phosphoric acid). In actual analysis, samples found in the hands of retailers run from 5 to 8 per cent. of phosphorus (equal to 11 to 18 per cent. of phosphoric acid), but usually between 5.75 and 6.6 per cent. of phosphorus (equal to 13 to 15 per cent. of phosphoric acid). They generally contain 0.45 to 1.3 per cent. of phosphorus (equal to 1 to 3 per cent. of phosphoric acid) in reverted form and about the same amount of insoluble.

In appearance an acid phosphate is usually a grayish

powder, sometimes quite dark in color, depending largely on the color of the original phosphate material used in the manufacture.

Dissolved bone, known also as *acidulated bone-meal*, bone superphosphate, etc., was the form of superphosphate that was made first. We do not need to pay much attention to it, because it is extremely rare; but in this connection it is well to call attention to a condition existing in the fertilizer trade in regard to the brand-names applied to superphosphates, many of which imply that the soluble phosphate is made from bone. Among these trade-names are the following: Acidulated bone, S. C. bone, soluble bone, dissolved bone, dissolved bone phosphate, besides special brand-names that have no particular meaning or reference to the composition of the product. To illustrate the common occurrence of the multiplicity of trade-names for soluble phosphates, we give a recent typical experience in the case of 40 different samples of superphosphates that were taken in the official collection of fertilizers in New York State in one season. They were sold under 20 different names, each name being represented one to seven times. In these 40 samples there was *only one genuine bone superphosphate* and yet in 20 samples a name was used that suggested the material to be dissolved bone. The term acid phosphate was used only seven times, although it should have been used 39 times, while the term superphosphate did not occur once. It should be added that there is a simple method for distinguishing superphosphate made with bone from that made with rock-phosphate; if the guaranteed statement of analysis includes nitrogen, the material is probably dissolved bone, but if only phosphoric acid is given in the guarantee, the material is acid phosphate.

It is not difficult to understand how this method of misrepresentation has originated. There has been a widespread belief that the soluble phosphoric acid in bone-superphosphate is superior as plant-food to that in dissolved rock phosphate, and farmers, in holding this belief, have been

encouraged to buy acid phosphate under the name of dissolved bone. The relative plant-food value of these two products will be considered later (p. 433).

Concentrated superphosphates.—If we treat tri-calcium phosphate ($Ca_3(PO_4)_2$) with free phosphoric acid (H_3PO_4) in place of sulphuric acid, we obtain a product that may contain as much as 17.5 per cent. of phosphorus (equal to 40 per cent. of phosphoric acid, P_2O_5), an amount about three times greater than is contained in the ordinary superphosphate or acid phosphate. This is known as double superphosphate, phosphoric acid superphosphate, concentrated superphosphate, etc. It is expensive to make and its use is practically limited to cases where long-distance transportation and consequent saving of freight is important. It is made in Europe in limited amounts.

Nitrate-superphosphate.—It has been proposed to substitute nitric acid for sulphuric acid in dissolving rock-phosphate, which would result in a product containing soluble calcium phosphate and, in place of comparatively valueless hydrated calcium sulphate (gypsum), the highly valuable calcium nitrate. For 100 pounds of pure tri-calcium phosphate, there would be required the equivalent of 252 pounds of pure nitric acid, and there would be formed about 75 pounds of soluble calcium phosphate and 106 pounds of calcium nitrate. The advantage of such a mixture would be the presence of plant-food nitrogen in addition to phosphorus and, therefore, a more concentrated preparation of plant-food, which would result in saving of freight. It is believed that this plan will prove feasible as soon as the artificial production of nitric acid has been sufficiently cheapened. In that case the nitric acid factory will be located near the supply of rock-phosphate.

Basic-slag phosphate is known also as Thomas phosphate powder, basic-iron slag, phosphate slag, etc. It is

a by-product formed in the manufacture of steel from iron ores containing a considerable amount of phosphorus compounds, when an excess of calcium oxide (lime) is used in the steel-making process. It is a heavy, black powder, usually of a fineness that enables 80 per cent. or more to pass through a sieve whose meshes are one-hundredth of an inch in size.

The use of basic-slag phosphate has never been very extensive in the United States, owing to the fact that most of our iron ores do not contain phosphorus enough to make a slag rich in phosphate. About twenty years ago or more, considerable amounts were made at Pottstown, Pa., containing 8 to 9 per cent. of phosphorus (equal to 18 to 20 per cent. of phosphoric acid) and selling under the name of "odorless phosphate." The price was too high to make the material an economical source of phosphorus and none has been found in market for some years. Basic-slag phosphate made at Troy and other places, has been offered for sale as a fertilizer, but its phosphorus percentage is low. Europe at present produces and uses practically all of the basic-slag phosphate of high grade. Within a few years it has been imported in limited amounts into this country, about 20,000 tons having been sold in 1910. The imported basic-slag phosphate usually contains about 7.5 to 8 per cent. of phosphorus (equal to 17 to 18 per cent. of phosphoric acid).

The exact composition of basic-slag phosphate is not satisfactorily settled as yet. Among the chief constituents, other than phosphorus, there are found compounds containing calcium (35 to 45 per cent.), magnesium (3.5 per cent.), iron (13 to 14 per cent.), manganese (6 to 7 per cent.), silicon (3 per cent.). The percentages given are only approximate. The exact form of combination in which the phosphorus occurs is a matter of some dispute. So far as present evidence goes, it is probable that most of the phosphorus is a double silicate and phosphate of calcium $(CaO)_5P_2O_5.SiO_2$, while smaller amounts exist as tetra-calcium phosphate $(CaO)_4,P_2O_5$ (p. 49). Such a compound as the silicate

contains about 12.8 per cent. of phosphorus (equal to 29 per cent. of phosphoric acid), 5.2 per cent. of silicon (equal to 11 per cent. of silica, SiO_2) and 40 per cent. of calcium (equal to 56 per cent. of lime, CaO). In regard to the form in which calcium is combined in basic-slag phosphate, generally less than 2, and often less than 1 per cent., is present as calcium oxide or so-called free lime, while the amount of carbonate is insignificant. The calcium therefore exists largely as phosphate and silicate. The use of basic slag-phosphate as a fertilizer will be considered later (p. 436).

Wiborg and Wolter phosphates.—As a matter of information rather than of practical importance, we briefly call attention to some European manufactured phosphate products prepared by heating apatite (p. 264) with sodium carbonate, feldspar or other materials. The product of one process is known as Wiborg phosphate and of another as Wolter phosphate. The resulting preparations contain phosphorus compounds in readily available form.

Palmaer phosphate, a European product, is the most recent commercial material in this line. It has the special advantage of being able to utilize the mineral apatite, which is not adapted to the manufacture of superphosphate by ordinary methods. The operation consists in treating the mineral phosphate with chloric or perchloric acid generated by electricity from the sodium salts. The product contains 36 to 38 per cent. of phosphoric acid (16 to 17 per cent. of phosphorus) in the form of di-calcium or "reverted" phosphate, 95 per cent. of which is available. Experiments indicate this material to be fully as effective as superphosphate and more so than basic-slag phosphate.

CHAPTER XVI

POTASSIUM-CONTAINING MATERIALS

The various materials we shall consider as the more common sources of agricultural potassium are the following: (1) Potassium chloride, (2) potassium sulphate, (3) potassium and magnesium sulphate, (4) kainite, (5) carnallite, (6) sylvinite, (7) potassium nitrate, (8) wood-ashes, (9) cottonseed-hull ashes, (10) tobacco waste, (11) rock-potash, (12) by-products of sugar-mills.

Wood-ashes constituted the first important source of potassium compounds used in agriculture, but the chief source of supply for the past 30 years or more has been the output of products from the Stassfurt mines in northern Germany. Before taking up the individual materials, we will briefly consider some facts of general interest relating to these German potash mines.

Products of German potash mines.—After having been used for the purpose of mining rock salt, the mines were abandoned about 1839. Later a further exploration of the beds by means of borings revealed large quantities of potassium compounds, especially chloride (muriate), and, about the year 1861, operations were begun to work the deposits for the commercial production of potassium compounds. As they exist in the deposits, the potassium compounds are more or less impure, being mixed with compounds containing calcium, sodium, magnesium, etc. The materials are first blasted out, and then removed from the mines, after which they are ground, dissolved in water and allowed to crystallize for the purpose of purification and concentration. By this process the impurities are more or less removed, depending on the degree of concentration and purity desired in the finished products, of which there are several grades. These are, therefore, more or less manufactured rather than natural products and include chiefly the chloride and sul-

phate, while some of the materials used for fertilizers are the crude products just as they are taken from the deposit, without having undergone any treatment for concentration or purification.

In general, the German potassium products, as they appear in the market, are gritty powders, varying in fineness and also in color, being white, dirty-white, gray or pink. They dissolve readily in water. Most of them have more or less of a tendency to absorb water and so become moist when exposed in damp places. They should therefore be stored only in dry places if kept for any length of time. While these potassium materials are used to a considerable extent in the United States in chemical industries for the manufacture of other potassium compounds, much the larger proportion is used for fertilizers. The Stassfurt mines are practically inexhaustible, estimates of their length of endurance varying from 200,000 to 600,000 years.

The annual output of the German potash mines is now between six and seven million tons, of which the United States takes over one million tons. Under the existing conditions of Germany's monopoly of the world's potash supply, the number of mines in the Stassfurt field and the total output have increased rapidly. In 1900 there were 12 mines and in 1909 there were 52; in 1910 there were 72, and the number is still increasing.

Potassium chloride (KCl, p. 51), is commercially known as *muriate of potash;* it is a prepared product derived from the crude materials of the German potash mines, purified by special treatment. It is found in the market in four different grades of purity, as follows:

TABLE 25—GRADES OF POTASSIUM CHLORIDE IN MARKET

Grade	Per cent. of pure chloride (KCl)	Eaual to per cent. of potassium (K)	Equal to per cent. of potash (K_2O)
1	70-75	36.5—39.3	44.0—47.0
2	80-85	42.0—44.5	50.5—53.5
3	90-95	47.0—50.0	57.0—60.0
4	98	51.5	62.0

Most of the chloride (muriate) found in the fertilizer market contains about 80 per cent. of pure potassium chloride and is usually guaranteed to contain the equivalent of 50 per cent. of potash (K_2O), which is about equal to 41.5 per cent. of potassium. The chief impurity in the commercial muriate is common salt, which may vary from 7 to 20 per cent., but there are also small amounts of calcium and magnesium compounds. The United States imports annually about 200,000 tons of this product. For information regarding the use of potassium chloride as a plant-food see Parts III and IV.

Potassium sulphate (K_2SO_4, p. 51) is commercially known as *sulphate of potash.* It is another of the Stassfurt manufactured products. It comes into the market usually in two grades, containing 90 and 96 per cent. of pure potassium sulphate, which is about equal to 40.5 to 43 per cent. of potassium, or 48.5 to 52 per cent. of potash (K_2O). The usual form in commerce is that containing about 48 per cent. of potash (K_2O). The sulphate is used in much smaller amounts than the muriate, less than 50,000 tons a year coming to this country. The impurities in commercial potassium sulphate are small amounts of sulphates and chlorides of calcium, magnesium and sodium.

Potassium and magnesium sulphate, *or double potash-manure salts,* is a product prepared in the manufacture of the high-grade sulphate, usually containing about 40 per cent. of potassium sulphate, which is equal to about 18 per cent. of potassium, or 22 per cent. of potash; when thoroughly dried, it contains about 48 per cent. of sulphate, about equal to 21.5 per cent. of potassium or 26 per cent. of potash. It contains 30 per cent. or more of magnesium sulphate. It is used for tobacco and fruits.

Potash manure salts is a term applied to low-grade potassium chloride (muriate), containing about 16.5, 25 and 33 per cent. of potassium (equal to 20, 30 and 40 per cent. of potash). In addition to chloride, these materials contain large amounts of common salt, considerable amounts of

sulphate and chloride of magnesium, with small amounts of other compounds.

Potassium-magnesium carbonate is a manufactured product that has been lately offered for use in fertilizing tobacco and certain fruit crops. The material, being in dry, finely powdered condition, is ready for application at any time. It contains 35 to 40 per cent. of potassium carbonate (K_2CO_3, p. 51), which is equal to about 20 to 22.5 per cent. of potassium, or 24 to 27 per cent. of potash. It contains about the same amount of magnesium carbonate.

Potassium carbonate is now placed on the market in high-grade forms, 93 to 98 per cent. pure, containing 52.6 to 55.5 per cent. of potassium, equal to 63.2 to 66.6 per cent. of potash. It is used in the growing of tobacco.

Kainite. According to the most recent, authoritative description by the Potash Syndicate, the ordinary commercial term "kainite" is no longer used to denote one single mineral of definite composition, but to embrace a group of materials, including *kainite, "hardsalt"* ("hartsalz") and *sylvinite*. Hardsalt and sylvinite are no longer sold separately as such.

These materials, as taken from the mines, are much alike in appearance; they are crystalline and vary in color from white to yellow and red. In powdered form they are usually dirty-white or grayish, containing small fragments that are red, black or yellow.

The chemical composition of these materials varies considerably, and the mixture of commercial kainite, of which they form constituent parts, must necessarily vary more or less in composition, depending upon the composition and proportions of the individual constituents. The mixture that comes into market under the name of kainite is guaranteed to contain at least 12.4 per cent. of potash, equal to 10.3 per cent. of potassium, no guarantee being given as to whether the potassium is in the form of sulphate or chloride.

The pure substance known as kainite consists of potassium chloride, magnesium sulphate, and a small amount of water of crystallization ($KCl. MgSO_4. 3 H_2O$). The potassium was formerly believed to be in the form of sulphate, and the magnesium in the form of chloride, but the reverse is now known to be true, though the matter is immaterial as far as practical applications are concerned.

The mined material known as *hardsalt* consists largely of potassium and sodium chlorides, and of magnesium sulphate, the potassium averaging about 13.3 per cent., equal to 16 per cent. of potash.

The material taken from the *sylvinite* beds is largely made up of potassium chloride and sodium chloride. Some strata of sylvinite contain 25 to 30 per cent. or more of potassium chloride (equal to 13.2 to 15.9 per cent. of potassium, or 15.8 to 18.9 per cent. of potash); others contain 20 to 22 per cent. of potassium chloride (equal to 10.6 to 11.7 per cent. of potassium, or 12.6 to 13.9 per cent. of potash).

Carnallite, in pure form, is a chloride of potassium and magnesium, but, as it comes from the mines, it is in a crude, impure form, being mixed with common salt, magnesium sulphate, etc. This crude carnallite is the largest part of the material taken from the potash mines and it is the chief source of the manufactured products. In the condition in which it is taken from the deposits, it appears white, red, gray or yellow. The crude carnallite contains about 13.5 per cent. of potassium chloride (equal to about 8 per cent. of potassium or 9.5 per cent. of potash.) Carnallite absorbs moisture rapidly and is, therefore, much more difficult to handle than kainite. On account of its low percentage of potassium, its cost of transportation makes the potassium more expensive.

Other crude salts.—The following materials, not of much commercial importance, are also mined at Stassfurt: (1) *Polyhalite*, a mixture of sulphates of potassium, magnesium and calcium, containing 12.5% to 13.25% potassium

(equal to 15 to 16 per cent. of potash). (2) *Krugite*, similar to polyhalite, but containing much more gypsum and only about 8.5 per cent. of potassium (equal to 10 per cent. of potash). (3) *Kieserite*, consisting mostly of magnesium sulphate. (4) *Bergkieserite*, a mixture of carnallite and kieserite, containing, along with much common salt, sulphate and chloride of magnesium, about 12 per cent. of potassium chloride (equal to about 6.25 per cent. of potassium or 7.5 of potash). (5) *Schoenite*, consisting mostly of sulphates of potassium and magnesium and containing about 22.5 per cent. of potassium (equal to 27 per cent. of potash). This has little or no commercial importance on account of the small supply.

Potassium nitrate.—See page 52.

Wood-ashes at one time constituted the chief source of supply of potassium in commerce and agriculture. Not only is the available supply small now but the percentage of potassium present averages less than formerly. So-called Canada, hard-wood, unleached ashes, supposed to represent the best quality, formerly contained over 4 per cent. of potassium (equal to 5 per cent. of potash); the percentage is now more often under 3.5 per cent. of potassium (or 4 per cent. of potash) and may drop to one-half this amount. It is obvious that wood-ashes should be purchased only under a definite guaranteed percentage of potassium. In wood-ashes the potassium is mostly in the form of carbonate (K_2CO_3, p. 51). When of good quality, wood-ashes contain 4 to 6 per cent. of potassium (or 5 to 7 per cent. of potash) and 0.6 to 0.9 per cent. of phosphorus (or 1.5 to 2 per cent. of phosphoric acid). Owing to the high price of wood-ashes, there has been considerable temptation to adulterate them, making a mixture of potassium chloride and some form of lime (calcium hydroxide or carbonate) and leached ashes, and sometimes other products of a worthless character. Leached wood-ashes contain about 0.8 per cent. of potassium (1 per cent. of potash) and 0.50 to 0.65 per cent. of phosphorus (1 to 1.5 per cent. of phosphoric acid), with 25 to 30 per

cent. of calcium (lime) compounds. In genuine wood-ashes, the calcium compounds may vary all the way from 20 to 50 per cent, but usually run between 30 and 35. In freshly burned ashes, calcium oxide (quicklime) is the chief calcium compound, but, in the case of ordinary wood-ashes, this is apt to be changed largely into carbonate by the time it is applied to soils.

Wood-ashes, even when pure and unleached, vary greatly in composition, according to the kind of wood, part of tree, age, method of burning, and care with which they are stored. Hard wood usually produces ashes containing more potassium than those from soft wood. When ashes have been exposed to the weather or leached, they contain much less potassium. Wood-ashes from lime-kilns and brick-kilns are often mixed with valueless refuse to such an extent as to possess little value as plant-food, though lime-kiln ashes usually contain larger amounts of calcium compounds than ordinary wood-ashes. Ashes from spent tan-bark of tanneries are low in plant-food value. The amount of potassium or phosphorus in coal-ashes is insignificant. For discussion of ashes in relation to their use as a fertilizer, see page 441.

Cottonseed-hull ashes are not now obtainable in appreciable amounts. They were formerly produced at cottonseed-oil factories in the South, when the hulls, after removal from the seed, were used as fuel. Such ashes are very variable in composition, containing from 12.5 to 25 per cent. of potassium (15 to 30 per cent. of potash) and 3 to 4.5 per cent. of phosphorus (7 to 10 per cent. of phosphoric acid). At the present time the hulls are, for the most part, ground and sold for cattle-feed.

Tobacco-waste consists of tobacco stems, stalks and waste materials coming from the manufacture of commercial tobacco products, all of which were at one time thrown away. These materials contain considerable potassium as well as nitrogen. Sometimes they are burned and the ashes

used for fertilizer; such ashes are very rich in potassium, but the nitrogen is lost by burning. Tobacco-waste ground fine makes a desirable source of potassium and nitrogen, where immediate availability is not required. It is also useful in adding to mixed fertilizers on account of the beneficial effect on the mechanical condition of the mixture.

Tobacco waste appears in three forms, stalks, stems and dust. Stalks include the portions of the plant above ground except the leaves; they consist of the main stalk and branches to which the leaves are attached. Stems include the leaf-stalk and ribs that make up the skeleton of the leaf, together with such other portions of the leaves as are rendered useless in the course of handling during the operation of making the tobacco into marketable forms. Tobacco dust includes fine particles that result from handling the leaves, mixed with more or less dirt. These materials give best results as plant-food when ground fine.

Tobacco-waste products vary much in composition. The nitrogen in stems varies from 2 to 3 per cent.; in stalks, from 3 to 4 per cent.; and in dust, from about 2 to 2.5 per cent. From one-third to one-half of the nitrogen in tobacco is present in the form of nitrate.

Phosphoric acid is present in small amounts, usually running between 0.5 and 1 per cent. (0.22 and 0.44 P).

Potash is contained in tobacco stems in amounts ranging from 5 to 10 per cent. (about 4 to 8 K), the usual variations lying between 6 and 9 per cent.; while, in stalks, the percentage is smaller, usually between 4 and 5 per cent. (about 3 to 4 K).

Tobacco products possess, in addition, insecticidal value, which makes them especially useful in the growing of small fruits and greenhouse crops.

Sugar-factory wastes.—The unmarketable molasses produced in the process of sugar-making contains potassium compounds in considerable amount. For example, ashes

from beet molasses may contain as much as 38 per cent. of potassium (45 per cent. potash), most of which is in the form of carbonate, with small amounts of chloride and sulphate. Low-grade molasses is sometimes mixed with other materials and applied directly to soils, but this practice should be accompanied with the application of generous amounts of calcium carbonate on account of the production of acids resulting from the fermentation of the sugar.

Ground feldspar (middle) produces no appreciable effect on yield in comparison with potassium sulphate (right). Rhode Island Station.

Potassium compounds in rocks.—At various times there has been considerable discussion as to the possibility of utilizing for agricultural purposes the potassium compounds known to be present in certain rocks, notably those consisting of the mineral feldspar. With some crops, under certain conditions, feldspar ground very fine has appeared to be used by plants, while it is worthless under other conditions. The question of its use must be regarded at present

as wholly in the experimental stage. It is extremely unlikely that ground potash-rock can ever take the place of readily soluble potassium compounds. It is quite probable that some economical commercial method will be devised for converting the insoluble potassium feldspar into a soluble form. In 1910, for example, a patent was granted for such a process, in accordance with which the potassium-containing rock is crushed, heated to high temperature, suddenly cooled in water and then ground fine. It is claimed that the process makes the potassium available to plants. More recently several new and promising processes have been developed. In view of the recent friction between the fertilizer manufacturers in this country and the German potash syndicate, which has an absolute monopoly of the world's present potash supply, some additional source of potassium is desirable.

In this connection, it may be stated that valuable potash deposits have been discovered in Austria and are to be rapidly developed. It is believed that valuable deposits exist in the United States, and our government has recently made an appropriation to prospect for such.

A most promising source of potassium supply is the inexhaustible growth of giant kelps, which form immense ocean meadows on the Pacific coast of North America. These seaweeds concentrate the dilute potassium compounds of the ocean to such an extent that one ton of dried kelp may contain 265 to 370 pounds of potassium (K) (equal to 315 to 440 pounds of potash (K_2O), or 500 to 700 pounds of potassium chloride). It is estimated that 100 square miles of kelp fields would furnish annually about 520,000 tons of potassium (equal to about 625,000 tons of potash or 1,000,000 tons of potassium chloride), worth not less than $35,000,000, or more than twice the amount we now pay Germany for potash salts.

CHAPTER XVII

FARM MANURE: COMPOSITION AND CHANGES

Farm manure consists of a mixture of three general classes of constituents: (1) The dung or feces of domestic animals, (2) their urine, and (3) materials used for bedding and often, in addition, miscellaneous waste products of the farm.

Farm manure is known under a variety of names, such as manure, mixed manure, barn manure, stable manure, farmyard or barnyard manure, etc. Usage of terms is not at all uniform; for example, some use the term barnyard manure, to mean cattle manure, while stable manure is applied to the manure of horses. The word manure is sometimes used of excrements alone and sometimes of the mixed excrements and bedding material. Mixed manure is generally applied to a mixture of manures of different animals with addition of bedding. The manure from any particular class of animals is designated by the name of the animal, as horse manure, sheep manure, etc. We shall use the general terms, farm manure, manure, mixed manure, barn manure, etc., with a single meaning, namely, the mixed excrements, solid and liquid, of farm animals in general, containing material added for bedding. We shall use the term excrements, as applying to the feces and urine not mixed with other materials. The manurial products from individual classes of animals will be indicated by the name characteristic of the animal producing the excrements.

In connection with the use of farm manure as a source of fertilizer materials, we are interested in the following points:

1. Composition of mixed farm manure.

2. Conditions affecting composition.
3. Care of farm manure.
4. Fertilizing value.
5. Methods of use.

The present chapter will be devoted to the composition and changes of farm manure, while the next chapter will consider the care, value and use.

PLANT-FOOD COMPOSITION OF MIXED FARM MANURE

We shall appreciate later how difficult it is to give a representative statement of the composition of a material which must of necessity vary greatly. In discussing farm manures, we are dealing with a mixture of animal excrements with other materials used as bedding, usually straw. The mixture may contain the excrements of one kind of animal or of several kinds. The bedding may be of several different materials. It seems desirable at the beginning of our discussion to start with some idea of the composition of mixed farm manure, including the approximately extreme limits of variation and what we may regard as a fair average. We shall limit our study of the composition of farm manure mainly to the nitrogen, phosphorus and potassium compounds.

TABLE 26—PERCENTAGE OF PLANT-FOOD CONSTITUENTS IN MIXED FARM MANURE

	Nitrogen		Phosphoric acid (P_2O_5)		Potash (K_2O)	
	Per cent.	Pounds in one ton	Per cent.	Pounds in one ton	Per cent.	Pounds in one ton
Lowest....	0.4	8	0.2 (0.09P)	4 (1.8P)	0.4 (0.33K)	8 (6.6K)
Highest....	0.8	16	0.4 (0.18P)	8 (3.5P)	0.8 (0.66K)	16 (13.3K)
Average...	0.5	10	0.25 (0.11P)	5 (2.2P)	0.5 (0.42K)	10 (8.3K)

P, phosphorus. K, potassium.

It will generally be convenient to remember that one ton of average mixed stable manure contains approximately

10 pounds of nitrogen,
5 pounds of phosphoric acid (2.2 lbs. phosphorus).
10 pounds of potash (8.3 lbs. potassium).

CONDITIONS AFFECTING COMPOSITION OF FARM MANURE

Variation in the plant-food composition of farm manure is produced by numerous causes, chief among which are the following: (1) Composition of fresh excrements, (2) kind and amount of bedding material in manure, (3) losses of plant-food constituents.

Variation in composition of fresh excrements of animals.—A study of the plant-food composition of the fresh excrements of different kinds of farm animals is desirable because this is the first factor in determining the plant-food value of farm manures. The composition of the excrements of farm animals varies greatly according to several conditions, among which the following are of special importance: (1) *The liquid and solid portions*, (2) *the kind of animals*, and (3) *the composition of the food consumed*.

Composition of solid and liquid excrements of different farm animals.—While the excrements of animals of the same kind vary greatly, and even of the same animal at different times, it is desirable that we have an approximate idea of their general plant-food composition. The following tabulated data, taken from the most reliable sources available, will serve to show the approximate amounts of nitrogen, phosphoric acid and potash in the fresh excrements of farm animals. We state in round numbers (1) the usual limits of variation of each constituent in the solid and liquid portions respectively and

(2) what may be regarded as the approximate average composition of solid and liquid portions, (a) separate and (b) mixed. In the case of water in fresh excrements, we give only the approximate average. In one column we state the approximate average percentage of the total excrements which the liquid and solid excrements respectively form.

TABLE 27—PERCENTAGE OF PLANT-FOOD CONSTITUENTS IN FRESH ANIMAL EXCREMENTS

Kind of Animal	Excrement		Water	Nitrogen	Phosphoric acid	Potash
	Portion	Per cent	Per cent	Per cent.	Per cent.	Per cent.
Horse	Solid	80	75	0.55 (0.50—0.60)	0.30 (0.25—0.35)	0.40 (0.30—0.50)
	Liquid	20	90	1.35 (1.20—1.50)	trace	1.25 (1.00—1.50)
	Mixed	—	78	0.70	0.25 (0.11P)	0.55 (0.45K)
Cow	Solid	70	85	0.40 (0.30—0.45)	0.20 (0.15—0.25)	0.10 (0.05—0.15)
	Liquid	30	92	1.00 (0.80—1.20)	trace	1.35 (1.30—1.40)
	Mixed	—	86	0.60	0.15 (0.07P)	0.45 (0.37K)
Pig	Solid	60	80	0.55 (0.50—0.60)	0.50 (0.45—0.60)	0.40 (0.35—0.50)
	Liquid	40	97	0.40 (0.30—0.50)	0.10 (0.07—0.15)	0.45 (0.20—0.70)
	Mixed	—	87	0.50	0.35 (0.15P)	0.40 (0.33K)
Sheep	Solid	67	60	0.75 (0.70—0.80)	0.50 (0.45—0.60)	0.45 (0.30—0.60)
	Liquid	33	85	1.35 (1.30—1.40)	0.05 (0.02—0.08)	2.10 (2.00—2.25)
	Mixed	—	68	0.95	0.35 (0.15P)	1.00 (0.83K)
Hen	Mixed	—	55	1.00 (0.55—1.40)	0.80 (0.35—1.00)	0.40 (0.25—0.50)

P, phosphorus. K, potassium.

Attention is called to the following points, which are brought out by a study of the data embodied in the preceding table:

(1) *Distribution of excrements between solid and liquid portions.*—The relative amounts of solid and liquid portions in fresh excrements vary greatly in the different classes of animals. In the case of horses, the solid portion is about four times as much as the liquid; in the case of pigs, the solid is only one and one-half times as great as the liquid portion. These amounts are, of course, only approximate averages; the proportions of solid and liquid

excrements vary widely with the same animal under different conditions.

(2) *Percentage of water.*—There is a marked difference in the average amount of water in the excrements of different kinds of farm animals. In the solid portion, the excrement of sheep contains least moisture (60 per cent.); that of cows, most (85 per cent.). In the liquid portion, the amount of water is least (85 per cent.) in the

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case of sheep and greatest (97 per cent.) in the case of pigs. In the case of poultry, there is, of course, no separation of solid and liquid excrements, but the amount of moisture in the combined excrement is much less than even in the solid portion of the excrement of the other animals under consideration.

(3) *Comparison of composition of solid and liquid por-*

tions.—In comparing the composition of the solid and liquid portions of animal excrements, we notice the following differences: (a) In respect to nitrogen, the liquid portion is much richer except in case of pigs; (b) in respect to phosphoric acid, the solid portion contains practically all. and the liquid portion only very small amounts; (c) in respect to potash, the liquid portion is much richer except in case of pigs. The richness of the liquid excrement in plant-food constituents is made more striking if we compare them in respect to their composition in the water-free or dried condition, as illustrated in the following table, in which only general average results are given:

TABLE 28—COMPOSITION OF DRIED OR WATER-FREE EXCREMENTS

Kind of Animal	Portion of Excrement	Nitrogen	Phosphoric acid	Potash
		Per cent.	Per cent.	Per cent.
Horse	Solid	2.20	1.20 (0.53P)	1.60 (1.33K)
	Liquid	13.50	——	12.50 (10.40K)
Cow	Solid	2.65	1.35 (0.60P)	0.65 (0.54K)
	Liquid	12.50	——	17.00 14.10K)
Pig	Solid	2.75	2.50 (1.10P)	2.00 (1.65K)
	Liquid	13.00	4.00 (1.75P)	15.00 (12.45K)
Sheep	Solid	1.90	1.25 (0.55P)	1.15 (0.95K)
	Liquid	9.00	0.35 (0.15P)	14.00 (11.60K)

P. phosphorus. K, potassium

Amounts of excrements produced by farm animals.—In order to make our discussion more complete, it is essential that we should not only consider the plant-food composition of the excrements of farm animals but that we should also know the total amounts and value of plant-food constituents annually produced by farm animals; and we will now take up this extension of our subject. The amounts of fresh excrements produced by farm animals are subject to wide variations, being gov-

erned by the kind of animal, age, amount of food, activity, etc. It will, however, be of some service to give approximate averages which can be used as a comparative basis of reference in estimating amounts of manure that can be reasonably expected from animals. The relative amounts of dung and urine vary with many conditions, and the proportions given below can be regarded as only rough approximations under average conditions. In order to be fairly specific and comparable, the results are stated on the basis of 1000 pounds of animal live weight during a period of one year.

TABLE 29—AMOUNTS OF EXCREMENTS PRODUCED FOR 1000 POUNDS OF LIVE WEIGHT BY FARM ANIMALS IN ONE YEAR.

Kind of animal	Total excrements	Solid	Liquid	Percentage of excrements in solid	Percentage of excrements in liquid
	Pounds	Pounds	Pounds		
Horse	18,000	14,400	3,600	80	20
Cow	27,000	19,000	8,000	70	30
Pig	30,500	18,300	12,200	60	40
Sheep	12,500	8,300	4,200	67	33
Hen	8,500	—	—	—	—

Amounts and value of plant-food constituents produced in excrements.—From the data contained in the table preceding and from the average percentages of plant-food constituents in fresh excrements, as given in the table on page 291, we are able to obtain the results contained in the table following, which shows the number of pounds of nitrogen, phosphorus and potassium produced on an average in the fresh excrements of different farm animals for one year, based on 1,000 pounds of live weight. The values in the last column are based on the following schedule of prices per pound: Nitrogen in liquid, 16 cents; in solid, 12 cents; phosphoric acid in

liquid, 5 cents, in solid, 4 cents; potash in liquid, 5 cents, in solid, 4 cents (p. 445)

TABLE 30—PLANT-FOOD CONSTITUENTS PRODUCED ANNUALLY IN EXCREMENTS BY FARM ANIMALS PER 1,000 POUNDS OF LIVE WEIGHT.

Kind of animal	Nitrogen		Phosphoric acid		Potash		Value of plant-food constituents
	Solid	Liquid	Solid	Liquid	Solid	Liquid	
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	
Horse	79	49	43 (19P)	——	58 (48K)	45 (37K)	$23.60
Cow	76	80	38 (17P)	——	19 (16K)	108 (90K)	29.60
Pig	101	49	92 (40P)	12 (5.3P)	73 (61K)	55 (46K)	30.00
Sheep	62	57	42 (18.5P)	2 (0.9P)	38 (32K)	88 (73K)	24.25
Hen	85	—	68 (30P)	——	32 (27K)	——	18.70

P, phosphorus, K, potassium.

The preceding table can be made of additional interest by the following supplementary table, in which the above data are presented in the form of percentages; for example, we state what percentage of the total nitrogen in the combined excrements is contained in the solid portion and what percentage in the liquid.

TABLE 31—RELATIVE AMOUNTS OF PLANT-FOOD CONSTITUENTS IN SOLID AND LIQUID EXCREMENTS

	Percentage of total nitrogen		Percentage of total phosphorus in		Percentage of total potassium in	
	Solid	Liquid	Solid	Liquid	Solid	Liquid
Horse	62	38	100	0	56	44
Cow	49	51	100	0	15	85
Pig	67	33	88	12	57	43
Sheep	52	48	95	5	30	70
Average ...	57	43	95	5	40	60

Somewhat striking differences exist in the case of different classes of animals. In general, most of the phos-

phorus appears in the solid excrement. In the case of horses and pigs, the yield of nitrogen is much greater in the solid excrement; in case of cows and sheep, the yield is approximately equally distributed between the solid and liquid portions. In the case of potassium, the excrements of horses and pigs show a larger amount in solid than in liquid, while the reverse is true of the excrements of cows and sheep, very large proportions appearing in the urine as compared with the dung.

If we compare the plant-food in the solid and liquid portions of excrements on the basis of valuation, using the prices given on page 295, we can prepare the following tabulated statement:

TABLE 32—RELATIVE VALUE OF PLANT-FOOD CONSTITUENTS IN SOLID AND LIQUID EXCREMENTS

	Percentage of nitrogen value in		Percentage of phosphorus value in		Percentage of potassium value in	
	Solid	Liquid	Solid	Liquid	Solid	Liquid
Horse	55	45	100	0	51	49
Cow	42	58	100	0	12	88
Pig	61	39	86	14	52	48
Sheep	45	55	94	6	26	74
Average ...	50	50	93	7	34	66

The relative value of the liquid excrement is higher in this table than in the preceding table because, in computing values, we give higher prices to the constituents in urine. For example, taking nitrogen, in Table 31, based only on the amounts present, 57 per cent. of all the nitrogen is in the solid excrement and 43 in the liquid; in Table 32, based on money value, 43 pounds of nitrogen in urine have the same money value as 57 pounds of nitrogen in the solid excrement. These figures indicate that about one-half of the value of the nitrogen and two-thirds that of potassium are in the urine.

From the data in Table 30 one can readily calculate the approximate amounts of plant-food constituents produced annually in the fresh excrements by a single animal of a given weight. For illustration, a table like the one following can be prepared and easily extended to include an animal of any special weight. We repeat the precaution that undue dependence must not be placed upon data thus obtained, since they are not intended to apply accurately in detail to all cases. They should be regarded only as serving for a convenient, rough basis, to be used when other desirable details are lacking.

TABLE 33—PLANT-FOOD CONSTITUENTS PRODUCED ANNUALLY IN EXCREMENTS BY FARM ANIMALS OF GIVEN WEIGHT.

Kind of animals	Weight	Nitrogen	Phosphoric acid	Potash	Value of plant-food constituents
	Pounds	Pounds	Pounds	Pounds	
Horse	900	115	38 (17P)	93 (77K)	$21.25
	1100	140	47 (21P)	113 (94K)	26.00
	1200	154	52 (23P)	124 (103K)	28.30
Cow	800	125	30 (13P)	102 (85K)	23.70
	900	140	34 (15P)	114 (95K)	26.65
	1100	172	42 (19P)	140 (116K)	32.55
Pig	100	15	11 (5P)	13 (11K)	3.00
	150	23	16 (7P)	19 (16K)	4.50
	200	30	21 (9P)	26 (29K)	6.00
Sheep	100	12	5 (2P)	13 (11K)	2.40
	150	18	7 (3P)	19 (16K)	3.60
Hens (100)	400	34	27 (12P)	13 (11K)	7.45
	500	43	34 (15P)	16 (13K)	9.30

P, phosphorus. K, potassium.

Influence of food upon composition of excrements.—Having studied the relation of the liquid and solid portions of excrements to the plant-food composition of fresh excrements in the case of different kinds of farm animals, we come now to take up the relation of the food consumed to the composition of the excrements. In the

case of farm animals in general, the plant-food composition and value of the fresh excrements are, as a rule, more dependent upon the composition of the food consumed than upon any other single factor. The nitrogen, phosphorus and potassium compounds that are taken in the food into the body pass from the body more or less largely in the form of excrements. It is therefore obvious why the amounts of these constituents present in the excrements depend chiefly upon the amounts present in the food consumed. In this connection we would call attention to a belief that has been quite prevalent among farmers to the effect that the process of animal digestion actually *adds plant-food* and that excrements owe to this their special value as fertilizers. This belief has come mainly from a confusion of amounts of plant-food with availability. There can be in excrements no more nitrogen, phosphorus or potassium than is contained in the food materials taken into the body; but these constituents, as they are found in excrements, are on the whole in more readily available forms as plant-food than in the original food before it is consumed and digested.

We will now consider (1) the amounts of plant-food materials present in some of the more common kinds of animal food, (2) the proportions recovered in excrements and (3) the digestibility of food in relation to plant-food availability in excrements.

Plant-food constituents in animal foods.—The amounts of nitrogen, phosphorus and potassium compounds in excrements primarily depend, as already stated, upon the amounts of these constituents in the food eaten. From the following table it can be seen that a given amount of concentrated foods, such as cottonseed-meal, linseed-meal, gluten-meal, etc., must yield the largest quantity of one or more plant-food constituents; then follow leguminous plants, such as alfalfa, clover, etc.;

next come cereals, and lastly root crops. The figures in the table give the amounts and values of the plant-food constituents in the different foods, or what would represent their general, relative plant-food value if used directly on crops. The prices used as a basis for the calculation of the relative money value are the following: Nitrogen, 12 cents a pound; phosphoric acid and potash, 4 cents a pound each.

TABLE 34—APPROXIMATE PLANT-FOOD VALUE OF SOME COMMON ANIMAL FOODS.

Kind of food	Nitrogen in one ton	Phosphoric acid in one ton	Potash in one ton	Value of one ton
	Pounds	Pounds	[illegible]	
Cottonseed-meal	140	60 (26P)	[illegible]	$20.40
Linseed-meal	110	36 (16P)	[illegible]	15.70
Gluten-meal	100	7 (3P)	[illegible]	12.30
Wheat bran	53	58 (26P)	[illegible]	10.00
Alfalfa hay	50	11 (5P)	[illegible]	8.25
Red clover hay	42	10 (4.5P)	[illegible]	7.05
Oats	40	16 (7P)	[illegible]	5.90
Corn fodder (with ears)	35	11 (4.8P)	18 (15K)	5.35
Corn	32	14 (6P)	8 (6.6K)	4.70
Corn-meal	30	13 (5.7P)	8 (6.6K)	4.45
Timothy hay	25	10 (4.5P)	20 (16.6K)	4.20
Wheat straw	10	3 (1.3P)	12 (10K)	1.80
Skim-milk	10	7 (3P)	4 (3.3K)	1.65
Beets	5	2 (0.9P)	10 (8.3K)	1.10
Corn ensilage	6	3 (1.3P)	7 (5.8K)	1.10
Turnips	4	2 (0.9P)	10 (8.3K)	0.95

P, phosphorus. K, potassium.

It is obvious that of two foods costing the same price and having equal feeding value, it is economy for farmers to use that one which contains the largest amount of plant-food materials. It is also noticeable that in nearly all the foods contained in the table, nitrogen is present in larger amounts than either phosphoric acid or potassium.

Proportion of fertilizing materials in foods recovered in fresh excrements.—In the case of farm animals in general, without special reference to kind or age, it is a

fair estimate that, on an average, about 80 per cent. of the nitrogen, phosphorus and potassium of the food consumed is recovered in the manure. Generally speaking, the excrements of working and fattening animals contain from 90 to 95 per cent. of the plant-food constituents present in the food eaten; in the case of cows giving milk and of young, growing animals, 50 to 75 per cent. When animals are not giving milk nor increasing in weight, the plant-food constituents in food and excrement are equal.

Digestibility of food in relation to plant-food value.— The solid portion of animal excrements consists largely of the undigested portions of food eaten. These undigested portions have not been acted on in the digestive process; this is a point of practical importance, because the portions of food that are not dissolved in animal digestion are likewise not easily made soluble in the soil by the ordinary processes of bacterial action. The plant-food constituents in the solid portion of excrements are therefore not quickly available for supplying crops. In the process of digestion, the portions that appear in the solid excrement, though remaining mostly undissolved, are mechanically changed and improved, because they are converted into a finer state of division, having gone through a process of softening and grinding. On this account the plant-food constituents in solid excrements undergo fermentation in the soil and become available more quickly than the same constituents in the food before it is used by animals. Another point worthy of notice in this connection is that in passing through animals the food becomes mixed with intestinal bacteria, which are responsible, in large measure, for the processes of decay that take place in the excrements, and render available the plant-food. From what has preceded, it is obvious that the larger the amount of indigestible matter in food, the larger is the amount of solid excrement

and, therefore, of slowly available plant-food. Coarse, bulky fodder materials produce large amounts of solid excrement; concentrated. ground foods produce smaller amounts of solid excrement.

The urine contains those portions of plant-food which have been digested and utilized in the animal body; its constituents are all in soluble form and are either directly available as plant-food or readily become so. The nitrogen, phosphorus and potassium compounds in the urine are, therefore, more valuable as plant-foods than the insoluble, slowly available constituents contained in solid excrement. It therefore follows that the more digestible a food is, the larger is the proportion of its plant-food constituents that will appear in the urine and the greater will be the plant-food value of the manure produced. Generally speaking, the richer the food is in nitrogen, the more digestible is the nitrogen and the larger the amounts of nitrogen in urine. The nitrogen compounds of the food are usually more extensively and completely transformed in digestion than are the phosphorus compounds and appear in the urine in larger amounts than in the solid excrements.

Relation of bedding to composition of farm manure.— Having considered the various conditions that influence the plant-food composition of the fresh excrements of animals, we are ready to take up the first factor of importance outside of the excrements that modifies the composition of manure, namely, the bedding or litter. This is used in stables primarily to furnish clean and comfortable places for animals to lie down. In relation to manure, bedding is used chiefly for the following purposes: (1) To absorb and retain the urine, thus preventing loss by drainage, (2) to increase the amount of slowly fermentable matter in manure in order to check and control the decomposition, (3) to increase the amount of organic matter and plant-food, (4) to retain

ammonia and prevent its escape into the air, (5) to make manure easier to handle, and (6) to influence in some cases both the physical and chemical action of manure.

The materials most commonly used are some kind of straw, such as wheat, oat, rye or barley. When easily procurable, muck and peat-moss are often used. Sawdust and shavings are being used in cities in increasing amounts, owing to the advancing cost of straw. The straws commonly used as bedding contain, on an average, about 0.5 per cent. of nitrogen, 0.3 per cent. of phosphoric acid (0.13 phosphorus) and 0.7 per cent. of potash (0.6 potassium). In general, the materials used for bedding are not rich in plant-food constituents.

In respect to *absorbing* power, ordinary straw can take up two or three times its weight of water. Fine-cut straw has much greater absorbing power than coarse straw; thus, straw in pieces an inch long absorbs about three times as much liquid as uncut straw. *Peat-moss* of good quality can absorb and retain as much as ten times its weight of water, and it also has the additional advantage of being able to absorb and retain ammonia. Muck is also an excellent absorbent. Manure containing liberal amounts of peat-moss or muck can be applied fresh, even to light soils, without disadvantage. Peat, or muck, adds considerable nitrogen to manure, but not in readily available form, but it is made more available by fermentation (p. 198). One slight disadvantage connected with the use of peat or muck is that the manure is a little more difficult to handle. The absorbing power of *sawdust* or *shavings* is two or three times that of ordinary straw; they add to manure about half as much nitrogen as straw and approximately equal amounts of phosphorus and potassium. Fine dry dirt, especially clay or loam with plenty of humus, is found a very convenient and efficient absorbent.

The *amount* of bedding used in farm manure varies

greatly according to various conditions. The chief point to keep in mind is to use enough to absorb the urine completely. The use of too much bedding material, especially of low grade, decreases the percentage of plant-food constituents, increases the cost of handling and may unfavorably affect the fermenting process (p. 211). In the table below we give the average amounts of bedding used in connection with the excrements of various classes of farm animals. The data are based upon the average amounts of excrements produced annually per 1,000 pounds of live weight. Assuming the bedding to be good average straw and to contain 0.5 per cent. of nitrogen, 0.3 per cent. of phosphoric acid and 0.7 per cent. of potash, we indicate the amount of plant-food constituents furnished by the bedding. With the exception of the data for steers, the figures in the last column are obtained from the table on page 295, by adding the value of plant-food in the bedding and in the fresh excrements. The data in the table are based on the assumption that all the excrements, both liquid and solid, are saved without loss. The values given represent, therefore, conditions that are more favorable than those prevailing in actual practice.

TABLE 35—PLANT-FOOD IN MIXED EXCREMENTS AND BEDDING FOR ONE YEAR PER 1,000 POUNDS OF LIVE WEIGHT.

Kind of animal	Weight of mixed excrements	Weight of bedding	Weight of total manure	Nitrogen	Phosphoric acid	Potash	Value of plant-food
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	
Horse	18,000	6,000	24,000	158	61 (27P)	145 (120K)	$29.60
Cow	27,000	3,000	30,000	171	47 (21P)	148 (123K)	32.60
Pig	30,500	6,000	36,500	180	122 (54P)	170 (141K)	36.00
Sheep	12,500	7,000	19,500	154	65 (29P)	175 (145K)	31.25
Steer	15,000	3,000	18,000	135	54 (24P)	72 (60K)	21.25
Hen	8,500	——	8,500	85	68 (30P)	34 (28K)	18.70

P, Phosphorus. K, potassium.

It is noticeable that the figures in the last column vary considerably from those given by other writers, being usually considerably lower. This is due to two reasons. First, too high prices are often assigned to the nitrogen, phosphorus and potassium in stable manure. When we consider the slow availability of the plant-food in the solid excrement and in the bedding, values should be assigned which represent approximately, at least, the actual plant-food value in comparison with commercial forms. The values assigned (p. 295) are believed to be fairly generous when all facts are considered. The second reason why too high values are often given for the annual manure product of animals is that the analytical data upon which the calculations are based are altogether too high for average conditions. This is well illustrated in the case of hen manure. Some have estimated the annual output per 1,000 pounds of live weight as high as $50 or $60 or even more. The writer has taken great care to collect all available reliable data and has been furnished some very valuable unpublished figures by Mr. W. P. Wheeler of the New York agricultural experiment station. These data do not justify the large results usually published.

From the data in the preceding table, we obtain the following average values for *one ton* of manure in the case of different farm animals:

TABLE 36—APPROXIMATE VALUE OF PLANT-FOOD IN ONE TON OF AVERAGE MANURE.

Horse	$2.50
Cow	2.20
Pig	2.00
Sheep	3.20
Steer	2.35
Hen	4.40

COMPOSITION OF FARM MANURE AS AFFECTED BY LOSS OF PLANT-FOOD CONSTITUENTS

Up to this point we have considered how the composition of farm manure is influenced by the composition of the fresh excrements and the bedding materials, the two factors which control the composition of the manure so far as its usual constituent materials are concerned. We should not need to go farther in our study of composition of farm manure, if all excrements were saved without loss and if no chemical changes took place in the manure; but losses of plant-food do take place under ordinary conditions and necessarily affect the composition of the manure. Such losses may be due to one or all of three causes: (1) Loss of urine in stable, (2) loss of soluble plant-food by leaching, (3) loss of nitrogen by fermentation.

Loss of urine.—It is shown on page 296 that, taking the average for farm animals in general, one-half of the value of the nitrogen and two-thirds of that of the potash excreted are found in the urine; or, expressed on the basis of the total plant-food in urine and dung, about 50 per cent. of the value is in the urine. When inefficient efforts, or none at all, are made to save the urine by use of absorbing materials (p. 301), it can be readily understood that large proportions of plant-food are lost and, as already pointed out (p. 300), *the portions thus lost are the most readily available forms of plant-food in the manure.* Too often these valuable constituents are allowed to run to waste through the cracks of the stable floor.

Loss by leaching.—The losses of plant-food in farm manure, as a result of leaching by exposure to rain, have been studied at several experiment stations in America and Europe. All results indicate marked loss of valuable constituents, including, not nitrogen compounds alone,

but phosphorus and potassium compounds as well. The method too commonly employed by many farmers is to throw the manure every day from the stable into the adjoining barnyard, where it lies for months unprotected from rain, sun and wind, often directly under the eaves of the barn. Investigations show, in brief, that in the course of six months stable manure may lose 60 to 70 per cent. of its plant-food constituents; in two months, when rainfall is fairly abundant, half or more of the plant-food value may be washed out. Leached manure necessarily shows greatly decreased effect on crops as compared with the unleached. In general, it is safe to say that, under the usual careless manner of storing farm manure out of doors, *over one-half of the plant-food value is lost.* An important fact in connection with this loss is that *the portions dissolved out in leaching are the most readily soluble and therefore the most quickly available as plant-food.* The losses by leaching are not confined to the liquid portion of manure, but the solid excrement may in the course of a few months lose nearly one-half of its nitrogen and more than half of its phosphorus and potassium compounds. Taking into consideration both the amount and availability of the plant-food leached from stable-manure, it is not an exaggeration to say that two-thirds of the plant-food value is leached from much of the stable manure used on American farms, which means an average loss of $1.25 a ton at least.

Process of decomposition and loss of constituents.—It is a familiar farm experience to observe that stable manure rapidly undergoes characteristic changes, such as increase of temperature, development of marked odors, shrinkage in bulk and darkening in color. These changes are brought about by the action of various micro-organisms (p. 189), especially bacteria, yeasts and molds. The processes by which these changes are produced are complicated, especially since several different kinds of

action may be going on at the same time. We cannot attempt to do more than to call attention briefly to some of the more important changes that take place during the decomposition of manure in so far as they relate to losses of material.

The constituents in which we are most interested are the following: (1) Phosphorus compounds, (2) potassium compounds, (3) nitrogen compounds and (4) nitrogen-free organic compounds (carbohydrates, starch, sugar, etc.).

(1) *Phosphorus compounds* are rarely, if ever, in danger of any loss as the result of the decomposition of manure by micro-organisms. Although no loss of phosphorus is experienced, the insoluble phosphorus compounds contained in the solid excrement are more or less largely changed into available forms of plant-food. Therefore, decomposition affects the phosphorus compounds in manure mainly in a favorable way.

(2) *Potassium compounds* in manure undergo no loss as the result of decomposition changes. The potassium in the liquid portion of manure is usually converted into alkaline potassium carbonate sooner or later and in this form is useful in neutralizing acids that are formed in the decomposition of starch, sugar, etc. Insoluble potassium compounds in solid portions of excrements are changed during decomposition into more easily available forms of plant-food.

(3) *Nitrogen compounds.*—The most serious loss that takes place when manure undergoes decomposition is in relation to the nitrogen compounds. Results of experimental work indicate that under most favorable conditions about one-sixth of the nitrogen in manure is lost during decomposition and that, under ordinary conditions, not more than one-half of the nitrogen contained in fresh manure is likely to reach the soil. We can consider separately the nitrogen in the urine, which is soluble, and

that in the solid excrement and bedding, which is largely insoluble.

(a) Decomposition of urinary nitrogen.—The smell of ammonia about horse stables is an experience familiar to every farmer; it is especially noticeable in warm weather when one first enters in the morning a stable which has been shut close during the night. The urine of animals contains certain compounds which are the first to undergo bacterial change, resulting in the formation of ammonium carbonate, $(NH_4)_2CO_3$ (p. 42). This compound easily decomposes, forming ammonia gas, water, and carbon dioxide, as shown by the following equation:

$$\underset{\text{Ammonium carbonate}}{(NH_4)_2CO_3} = \underset{\text{Ammonia gas}}{2NH_3} + \underset{\text{Water}}{H_2O} + \underset{\text{Carbon dioxide}}{CO_2}$$

Ammonium carbonate decomposes very easily at higher temperatures and rapidly passes into the air; it also goes into the air more easily when the liquid containing the ammonia is exposed to evaporation by distribution over more extended surfaces.

The bacteria that convert urinary nitrogen into ammonia are always abundant in stables, and their action is extremely rapid, especially in warm weather. Urine mixed with loose dung, like that of horses, undergoes decomposition even more rapidly than when kept separate. Urine that is richer in nitrogen compounds, as in case of horses, produces ammonia more rapidly than that containing less nitrogen, as in case of pigs, for example.

Urinary nitrogen is subject to serious loss on account of its rapid conversion into ammonium carbonate, which easily decomposes into products that escape into the air unless precautions are taken to prevent. The loss of such ammonia can be prevented or largely reduced by the presence of sufficient moisture and by the use of absorbents, as explained more fully on pages 301–2.

(b) Decomposition of nitrogen in solid excrement and

bedding.—The nitrogen compounds present in the solid excrements of animals are largely insoluble, since they have already resisted the attack of the digestive fluids and of intestinal bacteria in animals and are, therefore, not easily changed further by the process of decomposition. The nitrogen compounds contained in bedding, such as straw or similar material, are, in part, at least, somewhat more easily decomposed than the nitrogen of solid excrement, but only slowly when compared with urinary nitrogen.

The rapidity of change, the kinds of products formed, and the amount of nitrogen lost by the insoluble nitrogen compounds of manure during decomposition, depend mainly upon the amount of air in the manure. We have already had occasion to point out the effect of admitting or excluding air upon the decomposition of organic matter (p. 120) and to call attention to the differences in the processes known as decay or fermentation in air (aërobic, p. 200) and putrefactive decomposition or fermentation without air (anaërobic, p. 201). Essentially the same results follow when these decomposition processes are applied to the insoluble organic nitrogen compounds of manure. The effect of presence or absence of air we will consider in connection with the following changes that may take place in the insoluble nitrogen of the solid portion of manure: (1) Formation of ammonia, (2) formation of free nitrogen, (3) conversion of soluble into insoluble nitrogen compounds, (4) production of nitrate nitrogen.

(1) *Formation of ammonia from insoluble nitrogen in manure.*—The organic nitrogen contained largely in insoluble and rather inert forms in the solid portions of animal excrements and of bedding (straw, shavings, peat, etc.), is acted upon by numerous kinds of micro-organisms.

When abundance of air is admitted to the manure, as

happens in a loose heap or on the outside of an ordinary pile of manure, aërobic bacteria are active, and the insoluble nitrogen compounds are broken down with comparative rapidity, especially in case of favorably warm temperature; under these conditions ammonia is formed rapidly and, at the temperature developed in the manure heap, is apt to be lost in considerable amounts by escape into the air. Moreover, the ammonia that does not thus escape into the air may be decomposed into free nitrogen and water by other bacteria (p. 210) and thus lost to the manure as plant-food.

When air is excluded from manure, which is the case on the inside of a well-compacted, moist manure pile, the insoluble nitrogen is attacked by putrefactive microorganisms, which slowly change it into various other nitrogen compounds and sooner or later into ammonia. When formed under these conditions, the loss of ammonia by escape into the air is slight, unless the manure pile is allowed to become dry or is forked over and exposed directly to the air.

(2) *Formation of free nitrogen.*—The formation of free nitrogen from ammonia may occur when air is freely admitted to manure, as already stated above. Free nitrogen may also be produced by denitrification when nitrate nitrogen formed on the outside of a manure pile has been washed into the inside by rain.

(3) *Conversion of soluble into insoluble nitrogen compounds.*—Throughout all parts of a manure pile, immense numbers of bacteria are vigorously at work as long as conditions are favorable, and, it should be remembered, these bacteria must have nitrogen as food for their own use. When they can obtain it in soluble forms, they use these by preference. Therefore, in the process of decomposition of manure, bacteria appropriate to their own use ammonia or other soluble nitrogen compounds, which they convert into insoluble forms by storing it in their own

bodily substance. The nitrogen thus used is, however, not lost, because it is again changed into soluble forms when the bacteria die and themselves undergo process of decomposition. The amount of insoluble nitrogen thus formed varies according to different conditions, but it may be stated that, in general, the longer manure is kept under conditions preventing access of air, the larger is the proportion of insoluble nitrogen and the smaller the proportion of soluble nitrogen. For this reason, old manure, commonly known as well-rotted, is less active than fresh manure, which is rich in ammonia.

(4) *Production of nitrate nitrogen.*—Since nitrate nitrogen is formed only in the presence of oxygen, it can be produced only in those portions of manure that contain abundant air supply. In a moist, well-compacted pile of manure, nitrate is not produced except in the outer layers. This, if exposed to rain, is washed into the interior and then, in the absence of air, it may be converted into free nitrogen and lost or may be changed into insoluble nitrogen in the bodies of the active bacteria. Farm manure is not apt to contain much nitrogen in nitrate form, unless it has undergone a long process of fermentation under special conditions not commonly prevailing in manure piles. It is expected, in the use of farm manure, that the production of nitrate will take place chiefly after the manure has been incorporated in the soil.

(5) *Changes in nitrogen-free organic compounds in manure.*—Thus far we have not considered what happens during the process of decomposition to the large amount of nitrogen-free material, which constitutes so large a part of the dry matter in solid excrement and in bedding. The changes and results are essentially the same as those taking place in the decomposition of organic matter in soils, which we have already discussed with some fullness (p. 120).

The constituent forming the larger part of the nitro-

gen-free organic compounds is the cellulose or fiber present in relatively large amounts in the undigested, coarse portion of solid excrements and in the straw or similar material used for bedding. When air has free access, the fibrous material is largely changed into carbon dioxide and water; it is, in fact, practically burned up and largely disappears (p. 120). This occurs to some extent on the outside of a loose manure pile before it has settled and become compact. The chief kind of change, however, is that which takes place on the inside of the manure pile in the absence of air and is caused by anaërobic organisms. The material is changed into a dark-brown or black mass and all traces of original structure disappear sooner or later, the fibrous substances disintegrating into a dark, fine, soft mass. Owing to these characteristic changes, the process of manurial decomposition is commonly called "rotting"; fermented or decomposed manure is often known as "rotted" or "well-rotted" manure.

This change is accompanied by shrinkage in bulk, owing to actual loss of material. In the original carbohydrate material, more or less of its carbon is changed into carbon dioxide gas and its hydrogen into free hydrogen or marsh gas (CH_4). It may be stated that, in general, from one-quarter to one-half of the dry matter originally present in manure is lost during the process of decomposition, the amount varying according to the conditions of decomposition and the length of time the process continues.

(6) *"Fire-fanging."*—In this connection, we will here call attention to an abnormal process which occurs in manure that is loose and dry, as for example, a mixture of horse manure and straw. There is throughout the manure a white appearance, as if it had been sprinkled with flour. This appearance is due to growths characteristic of fungi. Manure which has gone through this

experience is said to be "fire-fanged" and its value is regarded as being impaired.

Summary of decomposition changes of manure. Enough has been said to show that the changes undergone by manure are varied and complex; many of them are taking place at the same time and, in some cases, changes that are reverse in character. To give a more comprehensive view of all these changes, we will briefly summarize the main facts.

(1) *Decomposition of urinary nitrogen.*—The first change to occur is the formation of ammonia in urine; loss of ammonia by volatilization is apt to occur unless the process is carefully managed by keeping the manure moist and compact.

(2) *Decomposition of insoluble nitrogen.*—The insoluble organic nitrogen compounds contained in solid animal excrements and in bedding undergo putrefactive decomposition with formation, sooner or later, of ammonia.

(3) *Conversion of soluble into insoluble nitrogen.*—Ammonia and other soluble compounds of nitrogen are used in considerable amounts as food by the bacteria in the manure and are stored in their bodily substance in insoluble forms; nitrogen transformed in this way is not lost, but becomes available when the bacteria die and undergo decomposition.

(4) *Formation of free nitrogen.*—Under some conditions, the nitrogen of ammonia and of nitrates is decomposed with formation of free nitrogen and its consequent loss as plant-food.

(5) *Decomposition of nitrogen-free organic compounds.*—The portions of manure represented by fibrous materials like cellulose are disintegrated into a dark-brown or black mass of fine, soft material, in which all traces of original fibrous structure disappear sooner or later. During this change, carbon and hydrogen disappear in the form of gaseous compounds to such an extent that from

one-fourth to one-half of the original dry matter in the manure is lost. For this reason, manure shrinks in bulk during decomposition.

Differences in fresh and decomposed manure.—In speaking of partially decomposed or rotted or fermented manure, we usually mean, as nearly as it is possible to describe it, manure in which the fibrous material has been largely decomposed into a somewhat crumbly, dark-colored mass, the original structure of the materials having more or less largely disappeared. In respect to composition, fresh and decomposed manure differ in regard to the following points, assuming that the fresh manure is a normal mixture of urine and solid excrement and that the conditions of decomposition have been under good control.

(1) *Decomposed manure richer in plant-food constituents.* We have seen that fresh manure shrinks much in bulk, one ton of fresh manure forming only one-half to three-fourths of a ton of decomposed manure. Since this loss falls upon the organic nitrogen-free constituents that furnish no plant-food, the plant-food constituents are, as a result, concentrated in the portion remaining.

(2) *Nitrogen in fresh manure more largely soluble.*—The nitrogen in decomposed manure is more largely in insoluble form than that in fresh manure. The urinary nitrogen in fresh manure is entirely in solution; but, during the decomposition of manure, it is more or less used as food by bacteria and converted into insoluble form as an integral part of their bodies.

(3) *Phosphorus and potassium more soluble in decomposed manure.*—The soluble phosphorus and potassium in fresh manure largely remain so during decomposition, while the insoluble forms of these two constituents present in solid excrement and bedding become more or less soluble.

Relation of air to decomposition of manure.—Before leaving this portion of our discussion, we wish to em-

phasize the importance of controlling the air supply of manure during the process of decomposition. We have already seen that serious losses of nitrogen in the form of ammonia and of free nitrogen are due to forms of micro-organisms requiring abundance of oxygen, and that larger amounts of carbohydrate or nitrogen-free materials are converted into gaseous form in the presence of abundance of air.

The bacterial processes that use atmospheric oxygen take place with great rapidity and intensity when the air supply is large. The process is one of oxygen consumption, a form of burning, and results in the production of heat, the temperature increasing with the air supply. Farmers commonly speak of this process in manure as "heating" or "hot" fermentation. The temperature may rise as high as 150° F. (65.5°C.) in the outer layers of a manure pile just under the surface or on the inside of a loose pile. Temperatures above 130° F. (54.5°C.) are unfavorable, decomposing ammonium carbonate and driving off ammonia. When the air supply is limited or excluded, as on the inside of a compact heap, the temperature is usually below 100° F. (37.8°C.).

The presence of moisture in large amounts tends to exclude air and therefore favors anaërobic instead of aërobic decomposition. It is largely the difference in moisture and, consequently, the amount of air present, that makes the manure of different animals decompose with different degrees of ease or rapidity. The manure of horses and sheep, on account of dryness, porosity and ready accessibility to air, decomposes easily; such manures are called "hot." The manure of cattle and pigs contains a high percentage of water, ferments slowly and is called "cold." Moist manure, like that of cattle, forms a hard, impervious coat on the surface when it dries and this protects the interior from rapid loss of moisture as well as makes it less accessible to external bacteria.

CHAPTER XVIII

FARM MANURE: CARE, VALUE AND USE

The fundamental object in caring for farm manures is to prevent loss of plant-food constituents as far as possible. Even under favorable conditions, it is practically impossible to prevent some loss of nitrogen, say 15 to 20 per cent. However, there is no difficulty in conserving all the phosphorus and potassium compounds. In considering methods of caring for farm manures, there are certain conditions to be observed in all methods; and, before considering details of special methods, we will consider some of the more obvious means of preventing loss of plant-food, mainly suggested by the discussion in the preceding chapter.

PREVENTION OF LOSS OF PLANT-FOOD IN STABLE MANURE

The usual losses of plant-food in farm manures can be largely avoided by observing the following conditions: (1) Use of mechanical and chemical absorbents, (2) regulation of the process of fermentation, (3) protection from leaching.

Use of absorbents.—Urine must be saved from mechanical loss, and, after ammonia is formed in it, this must be kept from escaping into the air. Such losses are prevented or lessened (1st) by means of water-tight floors and stable gutters, and (2d) by means of mechanical and chemical absorbents. For mechanical absorption, materials must be used which will take up the liquid and hold it securely without danger of loss from dripping when the manure is handled. The comparative absorbent powers of several different materials used for this purpose have been discussed

already in connection with bedding (p. 301). Several chemical materials are also used, which have a minor value as mechanical absorbents, but are more useful because they can form with ammonia chemical compounds which do not escape into the air. Of such materials, those most commonly used are land-plaster (gypsum), kainite and acid phosphate. Such materials as wood-ashes or lime, either slaked or unslaked, should *in no case* be mixed with stable manure, because they produce rapid decomposition and loss of nitrogen compounds. The use of ground rock-phosphate ("floats") with manure will also be discussed in this connection.

(1) *Land-plaster* or gypsum ($CaSO_4.2H_2O$, p. 55) has been much used for a long time. Its chief value is not because it possesses unusual power as a mechanical absorbent of liquid or of ammonia, a common belief, but because by chemical action it changes the easily volatile ammonia into a more stable form. This change can be represented as follows:

$$\underset{\text{Calcium sulphate,}}{CaSO_4} + \underset{\text{ammonium carbonate,}}{(NH_4)_2CO_3} = \underset{\text{ammonium sulphate,}}{(NH_4)_2SO_4} + \underset{\text{calcium carbonate}}{CaCO_3}$$

Ammonium sulphate is a compound in which the ammonia is held fast and is not in danger of loss by escape into the air. The calcium carbonate thus formed is, of course, beneficial to the soil (p. 374). There is, however, one objection to the use of land-plaster; during the anaërobic fermentation in the manure, it is possible that the sulphate may become converted into *sulphide* of calcium, which acts as a poison to plants. This possible danger is probably one that does not deserve serious consideration.

In order to be effective in manure, the land-plaster *must be finely ground and moist.* One method of use is to sprinkle it on the urine or moist dung. Some prefer to apply it on the stable floor after cleaning and before spreading bedding. In order to be of most use, the amount applied should be fairly large, not less than 100 pounds for one ton of manure,

which is rather more than is usually recommended. The amounts used daily for single animals would be approximately as follows: Horses, 2 to 3 pounds; cattle, 3 to 4 pounds; pigs, 8 ounces to 1 pound; sheep, 2 to 4 ounces; 100 hens, 8 ounces to 1 pound. The comparatively high cost of gypsum and its smaller efficiency, compared with acid phosphate, make its use a somewhat expensive practice.

PRODUCT OF ONE TON OF MANURE

13 years' average results. (Yield on one-sixteenth acre plots.)

Fresh manure treated with acid phosphate: Corn, 4.20 bushels; Wheat, 2.02 bushels; Hay, 330 pounds. *Fresh manure treated with floats:* Corn, 3.72 bushels; Wheat, 1.87 bushels; Hay, 302 pounds. *Untreated fresh manure:* Corn, 2.95 bushels; Wheat, 1.32 bushels; Hay, 178 pounds. *Untreated yard manure:* Corn, 2.29 bushels, Wheat, 1.25 bushels; Hay, 100 pounds. OHIO STATION.

(2) *Kainite* (p. 281) sprinkled on manure tends to attract and hold moisture. The potassium and magnesium compounds in kainite tend, as in case of calcium in land-plaster, to change ammonium carbonate into more stable compounds, such as ammonium chloride and sulphate. Kainite has the advantage of being easily soluble and is therefore more

readily distributed through the manure and more completely utilized than land-plaster. The application is recommended of 50 pounds of kainite for one ton of manure. One precaution should be observed in the use of kainite or any similar material; it should be kept from direct contact with the feet of animals, since it is injurious. It is therefore best applied to fresh manure and covered with bedding or it may be applied and carefully mixed with the manure daily when the stable is cleaned.

(3) *Acid phosphate* or *superphosphate* (p. 271) contains a considerable proportion of gypsum (land-plaster), and, to this extent, its action is the same as that of land-plaster. The soluble calcium acid phosphate in superphosphate combines with ammonia easily and holds it firmly. Superphosphate is more effective than either land-plaster alone or kainite in holding ammonia. To be effective, about 50 pounds of high-grade superphosphate should be used for one ton of manure. Superphosphate, like kainite, should be kept from coming into direct contact with the feet of animals. The objection may be made that the soluble phosphoric acid of the superphosphate is changed into an insoluble form by combination with amm[illegible] This objection is not serious, since the phosphoric acid again becomes easily available in the soil. The use of superphosphate with manure should for reasons of efficiency and economy supplant land-plaster.

A mixture of acid phosphate and kainite may be used at the rate of 25 pounds or more of each for one ton of manure. This mixture has the advantage of increasing the amount of phosphorus and potassium, so that the treated manure contains plant-food constituents in proportions nearer to those commonly used on crops instead of being over-rich in nitrogen and poor in phosphorus.

(4) *Ground rock-phosphate* or *"floats"* has been quite extensively used in connection with stable manure at the rate of 100 pounds for one ton of manure. This, however, has no chemical action in combining with ammonia, and,

therefore, its behavior is that of a mechanical absorbent, like that of any inert, finely divided substance. The chief advantage appears to be that insoluble phosphate applied to fresh manure becomes slowly available to crops to which the manure is applied; some experimental results appear to indicate that the insoluble phosphate becomes available more quickly by being mixed with the manure just before application to the soil.

(5) *Sulphurous acid.*—There has been recently recommended another compound for use on manure to prevent losses during the decomposition process. The compound is a solution of sulphurous acid. This is sprinkled on manure freely. It combines with ammonia and soon changes to ammonium sulphate, which is in no danger of loss by escape into the air.

Regulation of the fermentation process.—We have seen that the plant-food constituent that is lost in the fermentation of manure is nitrogen and that this is lost by escape into the air in the form of either ammonia or of free nitrogen. We have also seen that the largest nitrogen losses in fermentation take place when the manure is dry and loose, furnishing ready access of air to all parts. While the loss of 15 to 20 per cent. of the nitrogen originally present in the manure is practically unavoidable, additional loss can be largely prevented by controlling the conditions of fermentation; and this can be done (1) by keeping the manure compact, (2) by keeping it moist, (3) by use of preservatives, and (4) by using old manure as a foundation of the manure pile.

(1) *Keeping manure compact.*—The rapid fermentation that results in loss of nitrogen in manure is caused by organisms that require an abundant supply of oxygen. In cutting down the supply of air in manure, this destructive kind of fermentation is prevented or kept under control. It is essential to keep the mass of manure, whether stored in a pile or some other way, as compact as possible; this can be

done by trampling after every addition is made to the mass. In the case of manure piles, the sides and tops should be kept as smooth as practicable in order to exclude air. Under conditions of proper compactness, the temperature does not become high enough during fermentation to cause serious loss of nitrogen.

(2) *Keeping manure moist.*—The effect of an abundance of moisture in the manure pile is twofold: (1st) It tends t

Effect of manure on growth of clover. No. 1, no treatment; No. 2, treated with manure. IOWA STATION.

keep the temperature down and thus prevents destructive decomposition of nitrogen compounds, and (2d) it shuts out the air and thus prevents rapid fermentation. Water should be added to a manure heap whenever signs of hot fermentation are apparent. One must, however, avoid adding an excess of water, by which is meant more than can be absorbed and held without draining away from the pile.

By keeping manure sufficiently compact and moist, one

prevents serious loss of nitrogen without checking the slower forms of fermentation.

In connection with this treatment, attention should be called to the decided advantage of mixing different kinds of fresh farm manures when they are available. Thus, horse or sheep manure, which is dry and porous and quick to ferment, should be mixed with cow or pig manure, which is very moist and compact, and slow to ferment.

(3) *Use of preservatives.*—We have already (p. 316) discussed the use of some substances which, when added to manure, combine with and firmly hold ammonia, preventing its escape into the air. Some of these materials, especially *acid phosphate* and *kainite,* have the additional power of retarding fermentation; they are poisonous to micro-organisms. When used in moderate amounts, rapid fermentation is prevented. On the whole, however, it appears advisable to depend largely upon keeping the manure compact and moist for the purpose of preventing rapid decomposition.

(4) *Use of old manure as foundation of pile.*—Experiments have shown that losses of nitrogen by fermentation can be largely controlled by using as a foundation of a new manure pile a layer of well-rotted farm manure, a foot deep or more. The explanation of the beneficial results of this treatment probably lies in the fact that the old manure gives off abundant amounts of carbon dioxide gas and expels, or, at least, dilutes the air in the fresh manure, thus diminishing the activity of the fermentation by reducing the air supply.

Protection from leaching.—When farm manure is to be stored for any length of time, it should be kept under shelter, if possible. When conditions compel the storage of manure outdoors, precautions can be taken to lessen greatly the loss by leaching. The pile should be made high enough to absorb and hold all the rain that falls on it without leakage. The sides of the pile should be kept as straight and smooth as possible, the top should slope toward the center a little,

and the heap should be made as compact as possible. It is not the rain that falls on the pile which causes loss, but the water which runs through the pile and drains away at the bottom.

SPECIAL METHODS OF CARING FOR FARM MANURE

In addition to what has been said about ways of preventing loss of plant-food constituents in farm manures, we will give a brief description of some special methods of storing and handling manure. Of methods in use we select the following for consideration, since they may be regarded as among the most practicable: (1) Covered yards, (2) deep-stall system, (3) composting, (4) special treatment of poultry manure.

Covered manure yards.—These are well-roofed sheds, with or without sides, and provided with water-tight floors, which may be used for storing stable manure during decomposition when it cannot otherwise be advantageously disposed of. The manure can be piled and kept under control by properly compacting the pile and moistening when necessary. Another use of covered manure yards amounts practically to putting the barnyard under cover, allowing the animals to run there. The manure from the stables is spread uniformly over this yard daily. The trampling of the manure by the animals keeps it compact and moist, and the decomposition is easily kept under proper control. Under this system the losses of nitrogen during decomposition are comparatively small, the manure is convenient for handling and the plant-food is in a good condition of availability. Excellent results have been obtained also by using the covered barnyard as a place for keeping cows all the while except during milking-time. Mangers for feeding are provided and enough bedding distributed to keep the animals clean. A simple modification of this system is

to put horse and cattle manure under shelter, as for example in the basement of the barn, where swine can work it over, adding their excrements and keeping the mass compact and moist.

Another modification of covered manure yard or shed is an inclosed structure, located conveniently near the stables, with a water-tight floor sloping slightly from the sides to the center. Thick walls and a shaded location will contribute much to control of the conditions of decomposition. A convenient plan for such a building is to have it wide enough to form piles of manure on each side and leave space enough in the center to drive through with a wagon. Upon the floor is daily placed the manure taken from the stables and a pile built up five or six feet high. In starting the pile, it will be found advantageous to place as the foundation a six-inch layer of well-fermented manure. The pile is kept moistened if necessary. Should liquid drain from underneath it should be put back on the pile or absorbed by muck, dry earth, or some other good absorbent. After a pile has been completed, it is allowed to ferment about a month in warm weather or two months in cold, when it is well to fork it over in order to make the fermented product more uniform in character and also to hasten the process somewhat by a moderate air supply. Water is added after the turning if the pile shows any signs of being dry. It is also well after turning manure to cover the pile with land-plaster, dry earth, muck or similar material to the depth of one or two inches in order to retain ammonia that might otherwise escape into the air. Slightly modified, this method may be used for making compost. Along with the stable manure may be thrown in any waste organic material from the house or farm. After the layer is about a foot deep, it is covered over to the depth of one or two inches with dry earth, muck, sod or similar material, and then another layer of manure, etc. The same precautions are taken to keep the pile moist and cool, and the process is the same in other respects as already described.

Deep-stall system.—A method of storing manure prevalent in Europe is to allow the manure to accumulate under animals in something like box-stalls, the floor of the stall being below the general level of the barn floor. The fresh manure is daily distributed in a uniform layer over the stall floor and covered with abundance of litter. The results are good in respect to the character of the manure produced, but the method is objectionable on sanitary grounds, at least for use with dairy animals.

Composting.—This method consists, in general, of forming a heap of fresh manure in alternate layers with absorbent materials, keeping as moist as necessary and turning over occasionally. The details vary in individual cases in respect to the absorbent and other materials used, the thickness of layers, size of heap, frequency of turning over, location outdoors or under shelter, etc. One method of making a compost heap is to use as a foundation about four to six inches of fine dry earth, or, better, peat or muck, or well-fermented manure. On this foundation a layer of fresh manure is spread of equal or greater thickness and then alternating layers of absorbent material (peat, muck or earth) and manure. Care is taken to see that the manure is sufficiently moist when first placed and that it be kept so all the while, in order to prevent too rapid fermentation. The addition of so much water as to cause drainage from the bottom of the pile is to be avoided. The use of the earth or muck is for the purpose of holding moisture and absorbing ammonia. The entire outer surface of the mass should be kept covered all the time with a coating of earth. In the course of six weeks or two months after a pile is completed, it is forked over, uniformly mixed and moistened if necessary and again covered with a layer of absorbent, unless used at once. This is for the purpose of increasing somewhat the air supply and making conditions more uniform through the mass; it also favors the formation of nitrates. In place of earth or muck for the alternating layers of absorbent material, one can use grass sod, a mixture very

popular with forcing-house composts. Composted along with manure or separately can be used any waste organic materials of the household or farm, such as kitchen garbage, dead animals, weeds, plant wastes, human excrements, etc. One advantage of composting such waste materials in addition to utilizing their plant-food, is that they can be made to decompose readily without the offensive odors characteris-

Yields of alsike clover on loess soil. From left to right, No. 1, no treatment; 1,500 lbs. No. 2, manure; 2,440 lbs. No. 3, no treatment, nurse-crop; 520 lbs. No. 4, manure and nurse-crop; 2,920 lbs. IOWA STATION.

tic of the decay of many waste materials under ordinary conditions.

The composted product can be made more valuable as a source of plant-food for crops by mixing with either the fresh or the fermented manure materials rich in phosphorus and potassium, such as bone-meal, ground rock-phosphate ("floats"), acid phosphate, bone-flour, kainite, muriate of potash, etc., as already suggested (p. 322).

Bones can be composted and reduced to a condition that enables one to grind them easily. This is done by mixing the bones with quicklime or unleached hard-wood ashes, covering with a thick layer of earth or muck to absorb ammonia and allowing to remain for some weeks.

In this connection attention should be briefly called to a method which has of late attracted some interest. This consists in treating manure, straw or any kind of organic material with a mixture consisting of quicklime, unleached wood-ashes, salt, saltpeter, land-plaster and night-soil. This treatment carefully applied would undoubtedly cause rapid changes, but special care, by a generous use of absorbent materials, would be needed to prevent loss of nitrogen. Quicklime or slaked lime can be used in very small amounts in any compost heap where rapid action is desired, but extreme caution must be used in keeping the heap compact and moist, and absorbent materials must be employed in abundance. The use of lime in this way will insure effective action of the compost when applied to soil. We should, however, advise the use of finely ground carbonate of lime in larger amounts rather than the use of small amounts of quicklime or slaked lime.

Special treatment of poultry manure.—Poultry manure is of sufficient importance to deserve a paragraph by itself. On account of its high percentage of nitrogen, poultry manure easily loses nitrogen by decomposition, especially in warm weather. It is therefore important to mix the manure while fresh with materials that will retard decomposition and act as absorbents. For this purpose, the following mixture is recommended: For 10 pounds of poultry manure, use 4 pounds of sawdust or dry muck, 4 pounds of acid phosphate, and 2 pounds of kainite, and at proportional rates for larger amounts of manure. One ton of such a mixture contains about 10 pounds of nitrogen, 65 pounds of phosphoric acid and 30 pounds of potash, furnishing a complete fertilizer of good quality adapted to general farm use.

FERTILIZING VALUE OF FARM MANURES

Until quite recent times, animal manures have always been the main source of supply of plant-food used in the growing of crops, and in many countries this is still true. In the light of our modern knowledge relating to soil fertility and the feeding of crops, the long-continued use of farm manures has been well justified. It is our purpose at this point to present in a comprehensive way some of the main reasons why stable manure has special value in relation to the growing of crops. The main points to be considered in respect to the fertilizing value of farm manures are the following: (1) As a source of plant-food, (2) as a source of organic matter, (3) as a promoter of useful organisms, (4) as a promoter of crop growth, (5) long-continued effects, (6) farm manure and conservation of fertility, (7) commercial and agricultural value, (8) unbalanced character of farm manure.

As a source of plant-food.—Stable manure contains nitrogen, phosphorus and potassium compounds, which are the constituents usually most needed in cultivated soils. When farm manure is properly cared for and applied, the plant-food constituents possess varying degrees of availability, portions of each being ready for immediate use and other portions becoming gradually available during the growing period of crops and, to some extent, during two or three or more seasons in succession. Generally speaking, farm manures are deficient in phosphorus in comparison with nitrogen and potassium and, in addition, nearly all of the phosphorus is in the solid portion of the manure and more or less largely insoluble, at least in the case of fresh manure.

As a source of organic matter.—The large amount of organic matter in stable manure is an important factor in giving added value to its action in the soil. When manure is applied fresh, the organic matter is gradually decomposed in the soil and its decomposition products tend to make

available some of the insoluble plant-food constituents in those portions of the soil that come into contact with the fermenting substance and its products. In well-rotted manure, the organic matter is largely decomposed already. In addition to the value of its plant-food constituents, stable manure has, therefore, special value in maintaining the soil's supply of organic matter with all the attendant results in relation to improving soil texture, water-holding power, warmth, resistance to effects of wind, etc. (p. 134).

As a promoter of useful organisms.—Farm manures favorably influence the germ life of soils. Organisms are thus furnished the soil which can convert organic nitrogen into ammonia and others to change ammonia into nitrate nitrogen, while still others are added which decompose carbohydrate materials like cellulose. Manures also supply food material for the various organisms that are desirable in soils.

As a promoter of crop growth.—Numerous experiments, in which the use of stable manure and commercial fertilizers has been compared, have shown beyond question that the plant-food in properly handled manure has, in the long run, a crop-growing value quite equal to the same amount of plant-food in the form of commercial fertilizers, while the organic matter of farm manure gives it a decided advantage in the many cases where organic matter is deficient in soils. The crop-growing ability of most soils may be maintained indefinitely by the exclusive and abundant use of stable manure; but whether this is the most economical source of plant-food depends upon special conditions, which must be taken into consideration by each individual farmer.

Long-continued effects of stable manure.—A generous application (20 tons) of good stable manure shows a favorable influence on crops for several years following. Even more striking results in showing long-continued effects have been obtained by abundant applications of manure for several years in succession and then discontinuing or largely reduc-

ing the amount applied. The lasting effect of farm manures is due, in part, to the fact that some of its plant-food constituents become soluble only slowly and, in part, to the fact that some of the organic matter furnished may remain for several years and aid in gradually making available some of the insoluble plant-food in the soil.

Stable manure and conservation of fertility.—When it is kept in mind that about 80 per cent. of the plant-food constituents of the food of animals can be found in the manure, it is readily appreciated that the crops raised on a farm and fed to the animals belonging to the same farm do not constitute such an exhausting drain on fertility as when crops are removed from the farm. The loss of plant-food in the feeding of animals and in caring for the manure falls most heavily on the nitrogen compounds, which can be readily and inexpensively replaced by means of leguminous crops (p. 536), or by purchase of foods high in nitrogen to be fed on the farm.

Commercial and agricultural value.—The value of a ton of farm manure expressed in dollars and cents has been the subject of much discussion. From our knowledge of the extensive variations found in the composition of manure, it is obvious that, even when we know the amounts of plant-food constituents present, we are far from being able to place a precise value upon the manure which shall express its agricultural value, that is, what it is worth to the farmer in the growing of crops. Commercial values assigned to manures are based upon the total amounts of plant-food contained and do not generally take into consideration the availability of the plant-food constituents or the agricultural value of the organic matter present. These factors depend so much for their value to the farmer upon the kinds of crops grown, the condition of his soil, etc., that it varies according to the circumstances of each case. On page 295 we have given conservative commercial estimates of value based on the plant-food constituents of fresh manures. In

general, it should be true that the agricultural value is somewhat greater than is expressed in a statement based solely on plant-food constituents, since organic matter has some value. In regard to stable manure, the composition and history of which we have no means of knowing, any estimate of value nearer than 25 or 50 per cent. must be regarded largely as guesswork.

Unbalanced character of farm manure.—Before leaving our discussion of the fertilizing value of farm manure, we will consider in more detail a point to which we have incidentally referred elsewhere; namely, its pronounced effect as a nitrogenous plant-food. Farm manure in generous amounts, especially when used fresh, generally stimulates the growth of stems and leaves in a marked way, a condition characteristic of a high proportion of available nitrogen relative to available phosphorus and potassium. Under ordinary conditions, farm manure is regarded as a nitrogenous plant-food and as unbalanced with reference to the needs of most crops, relatively lacking in available phosphorus and potassium. This behavior of fresh manure of good quality is explained in large part when we consider that much of its nitrogen is in the form of ammonia, or soon becomes so, and under favorable soil conditions this is rapidly changed into nitrate, thus providing relatively large amounts of nitrate nitrogen long before the phosphorus, most of which is present in slowly available condition, becomes useful to plants. When we take into consideration the relatively small amounts of available phosphorus in most soils, this condition aids also in explaining why fresh manure so often acts as a one-sided, highly nitrogenous fertilizer when it is applied in large amounts. The question will naturally arise as to why well-decomposed manure does not produce the effects of overfeeding with nitrogen as much as, or even more than, fresh manure. We have been in the habit of thinking of well-decomposed manure as containing much nitrate nitrogen; as a matter of fact, its nitrogen is apt to be, on the

whole, more largely in forms that are much less quickly available than the nitrogen in urine contained in fresh manure. We have already pointed out the fact (p. 310) that, during the process of decomposition that goes on in a manure pile, bacteria are using large amounts of available nitrogen for their own food and are storing it away in their own body substance as insoluble protein, which becomes available only when the bacteria die and undergo decomposition. It is for this reason that we are not apt to find large amounts of nitrate nitrogen in well-decomposed farm manure, and that its nitrogen, on the whole, is much less quickly available than the urinary nitrogen of fresh manures. However, the case is somewhat different with available phosphorus and potassium, which are present in well-decomposed manure in larger amounts than in fresh manure. For these reasons, well-decomposed manure is to be regarded as more nearly approaching what we call a balanced combination of plant-foods than does fresh manure.

METHODS OF USING FARM MANURE

The effectiveness of farm manure as a fertilizer depends upon a number of conditions. No fixed rules for its greatest efficiency can be given which will apply uniformly under all circumstances. We can, however, state certain known facts and leave their application in specific cases to the individual farmer, who must adapt his practice to the particular conditions under which he is working. Among the points of greatest practical importance we will call attention to the following: (1) Advantages and disadvantages of use of fresh manure, (2) use of decomposed manure, (3) kind of soil, (4) kind of crops, (5) amounts to use, (6) methods of distribution, (7) when to apply, (8) depth to cover, (9) effective methods of general use.

Advantages of use of fresh manure.—Among the advantages of applying farm manures to the soil in as fresh condition as possible the following are prominent:

(1) *Plant-food utilized.*—Under most conditions, the application of manure when fresh utilizes the largest amount of plant-food. Losses of plant-food through leaching or destructive forms of decomposition are prevented. When used as a top-dressing, the portions leached by rain go directly into the soil; or, in case of no rain, the manure may dry with little loss from rapid decomposition. Mixed with the soil, fresh manure decomposes readily in warm or mild weather, its constituents being made gradually available as plant-food without risk of loss of nitrogen in the form of ammonia, except in some cases of light, porous soils exposed to high temperature.

(2) *Plant-food of soil made available.*—Not only are the plant-food constituents of farm manure, when applied fresh to soil, made more available, but the insoluble plant-food compounds of the soil itself are made more soluble wherever the decomposing manure comes into contact with the soil particles.

(3) *Desirable organisms supplied.*—Fresh manure contains various kinds of organisms which are effective in causing desirable chemical changes in the organic matter of the soil, and which the manure carries to the soil.

(4) *Lightening heavy soils.*—Fresh manure is most efficient for improving the texture of heavy clay soils, since it contains the organic matter that is utilized in the soil with all the consequent benefits (p. 134).

(5) *Prolonged effects.*—The plant-food constituents in fresh manure include both those that are quickly available and those that are slowly available. The soluble portions are immediately available or soon become so in the soil; the insoluble portions become available gradually, furnishing plant-food supplies continuously, not alone during one growing season, but through several.

(6) *Favors growth of foliage.*—Fresh manure used alone and in large amounts (p. 331) favors vigorous growth of stems and leaves. It is, therefore, useful in the case of

THE EFFECT OF FRESH AND WELL-ROTTED MANURE ON SAND AND CLAY SOILS

(25) Clay soil with fresh manure. (26) Clay soil with well-rotted manure. (27) ¾ clay and ¼ sand with fresh manure. (28) ¾ clay and ¼ sand with well-rotted manure. (29) ½ clay and ½ sand with fresh manure. (30) ½ clay and ½ sand with well-rotted manure.

(7) ¼ clay and ¾ sand with fresh manure. (8) ¼ clay and ¾ sand with well-rotted manure. (9) Sand with fresh manure. (10) Sand with well-rotted manure. VIRGINIA STATION.

many crops that furnish as their marketable product the stems and leaves, which are especially dependent upon rapid growth of foliage.

Disadvantages of use of fresh manure.—The principal disadvantages that may attend the use of fresh farm manures under certain conditions are the following:

(1) *Unfavorable effects on soil.*—Excessive application of fresh stable manure, especially on light, porous soils during hot, dry seasons, may either not ferment at all or may ferment too rapidly according to special conditions. If the manure contains large amounts of coarse vegetable matter from bedding, which persistently resists decay, a condition common in leached manure, the soil may be made so loose and open that the manure and soil both lose moisture to such an extent that decomposition of the manure will stop and the soil will be left in a condition unsuited to crops. On the other hand, if the soil contains enough moisture to favor decomposition, the action will take place so rapidly under the conditions of air supply and temperature that the soil will be heated and dried out to such an extent that it is left with greatly diminished water-holding power, owing to increased openness; the coarser the manure, the worse the injurious effect on the soil.

(2) *Unfavorable effect on crops.*—Under the conditions described in the latter portion of the preceding paragraph, when fresh manure containing abundance of urine is applied to light, open soils and undergoes extremely rapid decomposition, direct injury may be done to crops, known as "burning out." This results from the very rapid fermentation of urinary nitrogen in the presence of a large air supply and high temperature, producing quickly large amounts of ammonium carbonate and its nitric acid compounds, which become so concentrated by the rapid evaporation of water as to "burn" plants (p. 167), causing wilting and death. When the soil solution becomes so concentrated that it contains one part of soluble compounds, especially such as

Weed seeds and manure. The growing weeds came from the manure of a cow given feed containing weed seeds. The other side of the box, showing no growth of weeds, was treated with the manure of a cow given feed containing no weed seeds. VERMONT STATION.

ammonia and nitrate, in about 400 parts of water, it is liable to damage tender rootlets. When applied as a mulch about young plants, fresh manure may give off enough ammonia to injure foliage.

(3) *Carrier of weed seeds and disease germs.*—Fresh manure may carry to a soil weed seeds and germs of plant diseases. This disadvantage is usually overcome by making application of such manure to crops which are not affected

Piles of manure were allowed to decompose after weed seeds were placed in them. After 6 months, the seeds failed to germinate when planted; they were found soft and well rotted. MARYLAND STATION.

by the disease germs present or which are least troubled by weed seeds or which furnish an opportunity for destroying the weeds.

(4) *Not adapted to certain crops.*—Direct applications of fresh manure, especially in large amounts and on any but heavy soils, are undesirable for cereal and some other crops, since the quickly available nitrogen furnished by

the urinary nitrogen of fresh manure may injure the crop by causing too rank a growth of stems and leaves to the detriment of the quality or quantity of the marketable part of the crop.

Advantages of use of decomposed manure.—We have already called attention to the principal differences between fresh and partially fermented manure in respect to chemical composition and physical characteristics. Generally speaking, the phosphorus and potassium in partially decomposed manure are available to a larger extent than in fresh manure and are present in somewhat higher percentages. The nitrogen as a whole is in a somewhat less available condition. Such manure possesses some obvious advantages, among which we mention the following:

(1) *More even action.*—Whenever action of plant-foods is desired calling for available nitrogen in moderate amounts and for readily available phosphorus and potassium, rather than for the action of quickly available nitrogen in relatively large amounts, partially decomposed manure is well adapted to meet such needs. Instead of being a highly nitrogenous fertilizer in its effects, partially decomposed manure may properly be regarded as a more evenly balanced combination of plant-foods.

(2) *Advantage on light soils.*—Decomposed manures are useful for furnishing organic matter to light soils to improve their mechanical condition without risk of producing increased openness and consequent "burning out," which may result from the use of fresh manure. The decomposed organic matter in old manure increases the water-holding power of light soils.

(3) *Convenience in handling.*—Decomposed manure being more concentrated than fresh is less bulky for the same amount of plant-food and in this respect offers some advantage in convenience of handling.

(4) *Desirable micro-organisms supplied.*—Fermented

manures supply to soils beneficial organisms and also aid in making conditions favorable for increased activity of some desirable soil organisms.

(5) *Decomposition of weed seeds.*—When manure undergoes decomposition, the weed seeds are, in large part, rendered harmless, their power of germination being destroyed.

Kind of soil in relation to use of manure.—Generally speaking, farm manure, whether fresh or partly decomposed, can be used to advantage on soils that are deficient in organic matter. When it is desirable to introduce well-decomposed organic matter into the soil at once, decomposed manure can be used on any soil. When it is desired to have the decomposition of organic matter take place in the soil for the double purpose of making insoluble plant-food in the soil available and leaving a residue of humus in the soil, then fresh manure is preferable, especially on clayey soils. Fresh manure must be used with caution and preferably in comparatively small applications at one time on light, open soils, especially when there is liability of hot, dry weather (p. 121).

In relation to plant-food action, fresh manure is safer on heavy than on light soils, especially in large applications.

Kind of crops in relation to manure.—Farm manure, while beneficial for the growth of practically all common farm crops, requires for best results the observance of certain precautions in their use, especially with a few special crops. We will briefly consider some of the crops which respond most favorably to the use of manures, and some which may be injuriously affected unless manure is used judiciously with reference to the individual peculiarities of the crops in question.

It may be stated, in a preliminary way, that in all cases where the direct application of stable manure may do harm to the crop on account of the quickly available urinary nitrogen, the undesirable effects can be avoided by making a generous application of the manure to a suitable crop preced-

ing the one which is more sensitive. The first crop profits by the direct application, while the unused residue is left for the sensitive crop, as will be illustrated later. Another method is to apply the manure to the soil in the fall previous to growing the sensitive crop in the spring following. Still another method of overcoming the one-sided nitrogenous feeding effect of the urinary nitrogen of fresh manure is to apply generous amounts of acid phosphate and potassium chloride or sulphate.

(1) *Grass-lands* are generally much benefited by top dressing with farm manure, either fresh or fermented. The manure serves, in addition to furnishing plant-food, to form a mulch, often favoring somewhat earlier growth.

(2) *Root crops* usually respond most satisfactorily to generous applications of stable manure. However, some precautions in its use must be observed in the case of sugar-beets and potatoes. The use of excessive amounts of fresh farm manure, especially on light soils and loams, may cause beets to grow very large but with a low percentage of sugar; but on clay soils fairly large amounts (20 tons) of partially rotted manure may be used directly without harm. In case of potatoes, direct use of stable manure causes scab, and excessive amounts of fresh manure produce overgrowth of tops at the expense of the yield of tubers.

(3) *Corn, millet* and leafy crops, in general, which produce large amounts of foliage and stems, utilize to advantage generous amounts of stable manure when directly applied, whether fresh or rotted.

(4) *Cereals* are injured by large direct applications of fresh manure, the straw growing very large at the expense of the grain and lodging easily. Wheat and barley are particularly sensitive in this respect.

(5) *Tobacco,* when directly treated with large amounts of stable manure, produces large leaves of coarse texture and poor quality for use.

(6) *Flax* may also be unfavorably affected in quality by direct application of too much farm manure.

(7) *Garden crops* in general respond very satisfactorily to generous applications of manure.

(8) *Young trees, shrubbery, rose-bushes, etc.,* are greatly benefited by applications of stable manure, moderate in case of fresh manure, generous in case of well-rotted.

(9) *As a mulch* in connection with any growing plant, good stable manure is extremely effective and useful. Rotted manure is, of course, superior to fresh manure for mulching purposes on account of its greater water-holding power. Moreover, fresh manure, rich in urinary ammonia, when applied as a mulch about green plants, may injure the foliage, especially in warm weather. The ammonia volatilizes and burns the foliage.

7,420 lbs. hay per acre | **4,350 lbs. hay per acre** | **2,230 lbs. hay per acre**

EFFECT OF FARM MANURE ON TIMOTHY MEADOW. NEW YORK (CORNELL UNIV.) STATION

Amount of farm manure to use.—No statement can be made to meet all conditions in respect to the amount of stable manure to use in the growing of crops. Obviously it will depend upon a variety of conditions, such as the physical character of the soil, the amount of available plant-food in the soil, the condition and composition of the manure, the kind of crop, the frequency of application, etc. In general, 5 tons an acre may be regarded as a light application; 10 tons, moderate; 20 tons or more, heavy. It should be kept in mind that the larger amounts are better utilized when the soil is kept well supplied with calcium carbonate. In some cases, as on grass-lands, or where manure is used

in the first part of a well-planned rotation, large amounts are applied once in 4 or 5 years. Generally speaking, the most economical results are obtained by making smaller applications at more frequent intervals. The frequent use of light applications keeps the soil in a more uniform condition of fertility, and the nitrogen is utilized more completely, with less risk of loss by leaching from the soil.

In this connection one should take into consideration the amount of plant-food contained in manure. Taking good farm manure of average composition, one ton contains about 10 pounds of nitrogen, 5 pounds of phosphoric acid and 10 pounds of potash. On this basis we can prepare the following tabulated statement:

TABLE 37—AMOUNT OF PLANT-FOOD IN STABLE MANURE

	5 tons	10 tons	15 tons	20 tons
	Pounds	Pounds	Pounds	Pounds
Nitrogen	50	100	150	200
Phosphoric acid	25 (11P)	50 (22P)	75 (33P)	100 (44P)
Potash	50 (42K)	100 (83K)	150 (125K)	200 (166K)

P, phosphorus. K, potassium.

In applying 5 tons of good farm manure to an acre of ground, one is putting on the same number of pounds of nitrogen that is contained in 300 pounds of sodium nitrate, or in 1,000 pounds of fertilizer containing 5 per cent. of nitrogen; the same number of pounds of phosphorus that is contained in 200 pounds of acid phosphate, or in 300 pounds of a fertilizer containing 8 per cent. of phosphoric acid (3.5 phosphorus); and the same amount of potassium that is contained in 100 pounds of high-grade potassium chloride or sulphate, or in 400 pounds of kainite, or in 500 pounds of a fertilizer containing 10 per cent. of potash (8.3 potassium). When we consider the application of 20 tons of manure an acre, we are putting on very large amounts of plant-food as compared with the amounts usually applied in the form of commercial fertilizers. But a

mere statement of the number of pounds of plant-food applied to an acre in the form of farm manure is misleading, if we fail to consider at the same time the availability of the plant-food thus applied. It is doubtful whether, even under favorable conditions, we can reasonably expect more than one-third to one-half of the total plant-food in manure to be used by crops during the first season of application. Therefore, in considering the amounts of plant-food in the form of farm manure to supply crops during the growing season, it is usually safe to count on using two or three times as many pounds of nitrogen, phosphorus and potassium as are used with success in the form of commercial fertilizers of the best quality under similar conditions of soil and crop.

Methods of distribution.—In distributing farm manure on fields, three methods are commonly employed: (1) Distributing in heaps; (2) broadcasting from wagon; (3) applying in hill or row with seed.

(1) *Distributing in heaps.*—By this method manure is distributed in heaps, small or large, over the field and permitted to lie until it is convenient to spread it, whether the time be weeks or months. This method, while possessing the one advantage of temporary convenience, is open to several pronounced objections: (a) The labor of handling is increased; (b) the spots of ground under the heaps receive the leachings, the quickly available part of the manure, and are thus differently fertilized, as shown by results in unevenness of crops in respect to growth and maturing; (c) the manure may undergo rapid fermentation and lose much of its easily available nitrogen. Storing manure in large heaps on the field is less objectionable in respect to loss of nitrogen, provided the heap is kept moist, is well compacted, is carefully covered with a thin layer of fine earth, is so managed as to prevent drainage (p. 305) and is not allowed to lie too long before final distribution over the field. In this connection we will refer briefly to the droppings of animals at pasture. If undisturbed, uneven results of fertilization are invariably produced. In order to distribute these

heaps of excrements it is well occasionally to go over the field with a drag or some implement which will scatter the droppings more uniformly.

(2) *Applying broadcast.*—Under this method the manure is spread directly from a wagon over the entire surface of the field. The spreading is performed either by hand or by a manure-spreader. On farms where large amounts of manure are handled, a manure-spreader may properly be regarded as an economic necessity, since it distributes manure in an even manner, in a marked degree saving time and labor. Broadcasting is preferably practiced on fairly level fields where the manure is allowed to lie some time before plowing. If applied on steep hillsides some time before covering there is danger of leaching and washing down the slope, especially when the soil is frozen. Similarly, serious losses may be experienced in case of fields subject to flooding. The method of broadcasting manure directly from wagons has two marked advantages: (1) There is economy of time and labor in handling as compared with distributing in heaps before broadcasting; and (2) any leachings from the manure before being plowed under pass directly into the soil in uniform amounts over the field, so that no unevenness of crops results as in the case of leachings from distribution in heaps.

(3) *Applying in hill or row.*—This method is practiced when it is desired to have the effect of the manure concentrated where it will benefit the growing plants most quickly. It is especially applicable for forcing some kinds of garden crops. For example, it is customary to put a shovelful or so of manure in each hill in planting cucumbers, melons, squashes, etc. The same amount of manure can be made to go farther than when broadcasted. Rotted manure gives excellent results when used in this way.

When to apply manure.—Farm manure can be applied within wide limits as to time, depending on various conditions. Generally speaking, least risk of loss of ammonia occurs when manure is applied to soil only a short time

before plowing. One plan that has found considerable favor is to draw and distribute on the field in a uniform layer of any desired depth the fresh manure daily or at intervals as frequent as convenience permits, care being taken to treat the manure in the stable in some one of the ways already described (pp. 316-327). Direct distribution from stable to field has several pronounced advantages: (1) It economizes time and labor in handling. (2) It relieves the barn and its vicinity from the presence of accumulating masses of manure. (3) It is generally more convenient, especially during fall and winter, since farmers have more time then than in the spring when all kinds of work are pressing. (4) On the whole, this method brings to the soil the largest amount of plant-food, since risk of loss due to destructive fermentation, leaching, etc., is avoided. (5) The soluble portions of manure are gradually, completely and uniformly mixed with the soil. (6) The amount of nitrogen lost in the form of ammonia is small if the manure has been properly treated in the stable. Some experiments indicate that manure spread in thin layers over the surface of fields loses very little nitrogen either in the form of ammonia or of free nitrogen, provided it is not in a state of fermentation so active as to contain much ammonia when applied. In dry weather the manure quickly dries and fermentation stops; in wet weather the soluble portions are washed into the soil beyond danger of loss by escape into the air. There is, however, one distinct disadvantage in allowing manure to lie on the surface of the soil until its soluble nitrogen compounds have been largely dissolved and removed even though not lost to the soil. The soluble nitrogen compounds, as contained in fresh manure, are essential factors in the fermentation of the insoluble constituents of manure, and when they are once separated, as in leaching, the insoluble portion of the manure does not ferment as readily in the soil. On this account it is desirable, espe-

cially in case of light, porous soils, not to allow the manure to lie on the surface long, but to apply only a short time before being plowed in. It is possible also on light soils which leach easily that some small amount of the nitrogen may be lost to the soil by drainage if the manure is spread on the soil some months before it is plowed in for the use of crops. In the case of fields subject to flooding and of steep hillsides, the manure is best applied just before plowing.

Depth to cover manure in soil.—In heavy soils manure should be plowed under about 4 inches; if covered too deep in such soils, decomposition is delayed or prevented by exclusion of air. In light, porous soils the manure may be covered more deeply. Generally speaking, well-rotted fine manure gives best results near the surface, while coarse manure gives better results more deeply covered.

Effective methods of using farm manure.—Among the best methods of utilizing farm manure in feeding crops and making soil conditions favorable to plant growth, we call attention briefly to the following:

(1) *Use in rotations with commercial fertilizers.*—Farm manure is often used with advantage applied directly to the crop in a rotation that utilizes it to best advantage; with the succeeding crops of the rotation commercial fertilizers are used to supplement the plant-food needs according to the indications of experience. For example, farm manure is often applied directly for a corn crop, which is followed by wheat or any crop that might be injured by direct use of farm manure (p. 337) and for which an application of quickly available commercial fertilizer is used. Farm manure is generally used once in large application in 3 to 5-year rotations, and commercial fertilizer, in some form, is applied during the intervening period.

(2) *Fortifying farm manure with concentrated plant-food materials.*—The manure is treated in the stable or in the pile immediately after removal from stable with some such material as fine-ground rock-phosphate ("floats"),

bone-flour, acid phosphate, potassium salts, especially kainite, etc. (p. 316). This treatment increases the amount of phosphorus or potassium or both and, properly regulated, has the effect of making the proportions of plant-food constituents of the treated manure more nearly like those present in commercial fertilizers that are used with success.

Manure versus manure with rock-phosphate. The use of rock-phosphate in addition to farm manure increased yield 47 per cent. WISCONSIN STATION.

(3) *Farm manure and calcium carbonate.*—The action of farm manure is made more effective by keeping the soil well supplied with calcium carbonate. The application of manure to a "sour" soil increases rather than remedies the condition; with insufficient calcium carbonate in soils, there is loss of time and material in applying stable manure.

Farm manure an important farm by-product.—In closing our discussion of farm manure, we cannot do better than emphasize its value. *It should be regarded as one of the most valuable by-products of the farm.* As such, it should receive the care that will enable the farmer to realize its highest efficiency in the growing of crops.

CHAPTER XIX

GREEN-CROP MANURES

Green-crop manures or *green-manures* are crops grown for the purpose of being plowed under and thus making soil conditions more favorable for the growth of succeeding crops. They are known as cover-crops when following other regular crops, occupying the ground only part of the growing season, or when used in orchards, the object being, in part, to protect the soil during the latter part of summer and over winter, and, in part, to furnish organic matter for the soil. The plowing under of sod and of stubble and roots is a form of green-crop manuring.

The beneficial effects of green-crop manures were observed long before it was known in what particular ways they acted to produce better crops and numerous experiments have served only to confirm and emphasize as well as explain more fully the fact that green-crop manures favorably affect succeeding crops. The subject will be treated under the following divisions:

1. Effects.
2. Different crops used.
3. Conditions and methods of use.

EFFECTS OF GREEN-CROP MANURES

The beneficial effects obtained by the use of green-crop manures are briefly summarized under the following heads: (1) Organic matter, (2) conservation of soluble plant-food, (3) addition of nitrogen, (4) transfer of plant-food from subsoil to surface, (5) concentration of plant-food, (6) effect on bacterial life in soil, (7) in-

crease of available plant-food, (8) improvement of subsoil, (9) relation to surface of soil, (10) effect on growth of orchard trees.

A few of the crops used as green-manures are able to produce all of these effects; all are able to furnish material for humus, to diminish the loss of soluble plant-food and to influence the surface by their presence while growing, while many, in addition, increase the actual supply of soil nitrogen.

Organic matter.—The most extensive action of any green-crop manure is the furnishing of a supply of organic matter, the amount varying according to the crop and the extent of growth. The usual range of yield of green vegetable matter, including roots, may be placed between 5 and 10 tons an acre, though higher and lower yields may occur; this consists approximately of 1 to 2 tons of dry matter, and 4 to 8 tons of water. There is no way in which such large amounts of organic matter can be added to the soil so cheaply under agricultural conditions commonly prevailing. The decomposition of the vegetable matter is attended by all the beneficial effects characteristic of this important soil constituent (p. 134). The roots are first to decompose, then the more succulent portions of the green tops and finally the more woody parts.

Conservation of soluble plant-food.—On land that is not occupied with crops for a considerable length of time, as in case of land lying fallow after the removal of a crop during summer or early fall, there is danger of loss of nitrate nitrogen in one or both of two ways: (1) Nitrates are easily lost in drainage water and (2) under some conditions they are decomposed into free nitrogen (p. 210). Experiments have fully established the fact that when the soil is occupied by a crop, the soluble plant-food goes into drainage water in much smaller amounts, if at all, but is taken into the plants

and becomes a part of the crop growth. Moreover, under such conditions, nitrate nitrogen is in little danger of being lost as free nitrogen. The soluble plant-food is transferred into the crop, in which form there is little danger of loss under ordinary conditions. Crops having extensive root systems are especially efficient in thus collecting, concentrating and holding plant-food. Nitrogen as nitrate may be lost annually to the extent of 40

EXPERIMENT PLATS. NEVADA STATION.

pounds an acre on fallow ground. The losses are greatest on light soils. During the warm summer months, especially July and August, when nitrification is taking place most rapidly in the soil, nitrate nitrogen is lost more rapidly than at other times of year, other conditions being the same. When wheat is grown continuously on the same soil, without any cover-crops between, there may be lost from the soil 4 to 6 pounds of nitrogen for each pound used by the crop.

Addition of nitrogen.—Leguminous crops used as green-crop manures add to the amount of nitrogen in the soil, owing to their ability to use atmospheric nitrogen in their growth when their roots are properly supplied with nodules (p. 216). Green crops of this kind contain 50 to 100 pounds and more of nitrogen an acre, not including stubble and roots, the amount depending upon the kind, yield, maturity, etc., of crop. Including all the vegetable growth of the crop, roots as well as tops, the total amount of nitrogen usually runs from 100 to over 150 pounds an acre. Not all of this nitrogen is taken from the air, but a considerable portion is known to be, the exact amount varying according to the crop and conditions of growth. The nitrogen compounds in the vegetable matter of green crops undergo decomposition in the soil, with final conversion into nitrate nitrogen.

Concentration of plant-food.—In the case of plants whose roots penetrate the subsoil, nitrogen, phosphorus and potassium compounds are collected from all parts of the soil; and then when the crop decomposes in the upper layers of the soil, this food is concentrated within a more limited area of the soil than previously. In the case of leguminous crops, the concentration of nitrogen becomes greater than in other cases, since we have not only the nitrogen collected from the subsoil but also that taken from the air.

Increase of available plant-food.—The action of growing roots appears to be effective in making some unavailable plant-food available (p. 172), which is taken into the plant and, in case of green-crop manures, returned to the soil in forms that are more available than before use by the crop.

Transfer of plant-food from subsoil.—Crops with long roots gather from the subsoil considerable amounts of plant-food, thus lifting it to the surface and making it

available for the use of succeeding crops. Alfalfa is famous for the length of its roots, sending them down under favorable conditions anywhere from 12 to 30 feet or more.

Effect on bacterial life in soil.—In soils left fallow for a portion of the year, as in case of continuous wheat growing, bacteria prevail which actively destroy humus and set nitrogen free. These injurious bacteria are found to disappear for the most part in soils in which green crops, and especially leguminous crops, are incorporated as a part of a system of crop-rotation. In addition, the different kinds of bacteria that convert organic nitrogen into ammonia and nitrate nitrogen are found to flourish in the presence of the organic matter furnished by green crops.

Improvement of subsoil.—Those plants having long tap-roots penetrate the subsoil deeply and when the roots decay, extensive passageways are opened for the percolation of water and circulation of air.

Relation to surface of soil.—When used as cover-crops green crops serve to protect the surface of the soil from washing, especially on hilly lands, and, in case of light soils, from being blown about by high winds. Green crops on a soil during winter hold drifting snow, keeping the soil warmer and preventing injury to roots caused by alternately freezing and thawing. In some cases where the foliage is broad-leaved and extensive, the soil is shaded and protected from needless loss of moisture by direct evaporation.

Effect on growth of orchard trees.—Cover-crops in orchards compete with trees for plant-food, including water. In the case of soils containing nitrate nitrogen in such proportions as to cause the trees to make a prolonged, succulent growth of new wood, liable to injury by freezing in winter, cover-crops serve to use the surplus nitrogen, checking the growth of trees late in sum-

mer and inducing early maturity in wood of firm, hardy character.

DIFFERENT CROPS USED AS GREEN-MANURES

From the preceding statements, it is obvious that the purposes of green-crop manures are most completely fulfilled by those crops which have, in addition to heavy foliage and deep roots, the power to utilize and store atmospheric nitrogen. The particular kind of crop used as green-manure must depend upon the special conditions present in each case, such as climate, soil, kind of rotation, special objects in view, the value of the green-crop for forage, etc.

The crops used as green-manures can be conveniently divided into two groups: (1) The first group includes those plants which contain more or less nitrogen that has been obtained from the air, and which, therefore, when incorporated in the soil, actually add nitrogen to the soil's previous supply. These are commonly known as *nitrogen-gatherers* and those in actual use belong to the leguminous family of plants. (2) The second group includes those plants, the nitrogen of which is taken directly from the soil, and which give back to the soil only the nitrogen previously taken from it. These are commonly known as *nitrogen-consumers,* and include such crops as rye, buckwheat, etc.

Some of the more prominent characteristics that render individual crops suitable for green-manures will now be briefly discussed.

Nitrogen-gathering or leguminous green-crop manures. In the United States and Canada several leguminous crops are grown for partial or complete use as green-manures, among which the following are of most practical interest: Red clover, alfalfa, cowpeas, alsike clover, crimson clover, white clover, Canada peas, soy-beans,

peanuts, vetch, velvet beans, Japan clover, sweet-clover, beggar-weed, fenugreek, horse-beans, field-beans, lupine, sainfoin, serradella, and lentil. Only about one-third of these have become sufficiently established in practical use to call for more than mere mention. Each of these crops can be grown under best conditions only in more or less definitely limited areas. In the northern portions of the United States, red clover, mammoth clover, alsike clover, field-peas and common vetch are most commonly used; in regions having a moderate to warm temperate climate, cowpeas and crimson clover are extensively grown; in many parts of the West, alfalfa, clovers, cowpeas and soy-beans largely furnish green-crop manures.

For details in regard to the value and cultivation of leguminous crops for green manure, see pages 536-556.

CONDITIONS AND METHODS OF USE OF GREEN-CROP MANURES

In addition to the statements already made, there are other details that should be briefly considered before leaving the subject of green-crop manures. Under this head we shall take up the following points for discussion:

(1) When green-crop manures should be used.
(2) What crops should be used.
(3) Preparation for growing green-manure crops
(4) Relations to different soils.
(5) Time of plowing under.
(6) Crops to follow green-manure crops.
(7) Effect on succeeding crops.

When green-crop manures should be used.—The indiscriminate use of green-crop manures cannot be recommended. Used properly when conditions call for them, they are extremely effective; but, when used under some conditions, they may be either useless or else harmful. Green-crop manures can be used profitably in improving

soils that are poor in nitrogen and organic matter, since such soils are always defective in physical conditions. They are especially efficient on many light, sandy soils and also on very heavy clay soils. In orchards, they may be advantageously used as cover-crops.

On soils in good physical condition that grow good yields of crops, green-crop manures should be used

CRIMSON CLOVER. KENTUCKY STATION.

only at intervals sufficient to maintain the supply of organic matter and nitrogen; and this is best done ordinarily by using some leguminous crop as part of a regular rotation.

When farm manure can be had in abundance, as on dairy or stock farms, it is found most profitable to raise as green-manures only those crops which, like red clover and alfalfa, can be largely utilized for feeding animals, depending upon the roots and stubble, and supplementing with farm manure, as sources of organic matter and nitrogen supply.

The use of green-crop manures in dry regions is not practicable without irrigation, since with insufficient moisture, the vegetable matter decays with extreme slowness, leaving the soil filled with air spaces and promoting loss of water by evaporation.

What crops should be used as green-manures.—It is obvious that those crops should be used which are best adapted to the climate, soil, system of farming and the special purpose one has in view. Leguminous crops should be given preference when they can be grown satisfactorily. As to the particular legume to use, this must be determined mainly by the choice of the one that can be grown most advantageously under the special conditions present in each case. In this connection, the prominent characteristics of the different plants will be briefly reviewed. Some are perennials and some are biennials or annuals; some are summer or warm-weather crops and others are cool-weather crops, adapted to late fall and early spring growth. Thus, mammoth, alsike and white clovers and alfalfa are *perennial;* sweet clover is *biennial*, while red clover, though it may persist for three years, is more often grown for only two years continuously and may therefore be regarded as a practical biennial. These crops make slow growth at first, which is a serious objection to their use in cases where quick results are needed, as with soils deficient in humus. Of the annual legumes, the following are *summer* annuals: Cowpeas, soy-beans, peanuts, beans, velvet beans, common vetch and field-peas; while the following are winter annuals: Crimson clover, hairy vetch, and, in the South, common vetch and field-peas. These are adapted to use as cover-crops. In regard to the extent of root systems, red clover, mammoth clover, alfalfa and sweet clover are deep-rooted, and the roots alone may form from one-third to one-half of the plant; the other leguminous plants have comparatively short root systems,

constituting approximately one-sixth to one-tenth of the plant. All these as well as other individual characteristics must be taken into consideration in making a choice of the crop that will best adapt itself to the needs and conditions of the farmer.

Preparation for growing green-manure crops.—While most of the green-manure crops are not difficult to grow

COVER-CROP OF RYE AND VETCH; RYE, 6 FT. HIGH; VETCH, 4 FT. HIGH. DELAWARE STATION.

under proper climatic conditions, and several of them even on poor soils, yet there are some few precautions which should be observed if one expects success. The points to which special attention should be given are summarized as follows:

(1) *Preparation of soil.*—The soil should be put into fine tilth before seeding, especially in the case of leguminous crops.

(2) *Use of calcium compounds.*—Application of ground limestone or of slaked lime should be made if there is any indication of acidity (p. 140).

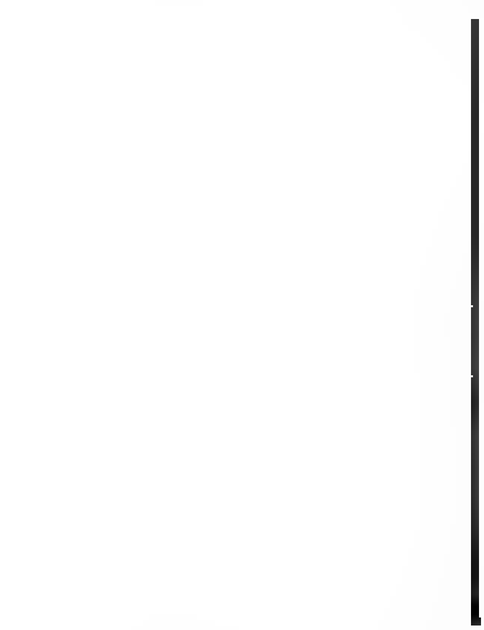
(3) *Addition of plant-food.*—In case of poor soils, it is usually desirable to use a small application of fertilizer (pp. 538-543). In case of non-leguminous crops, a complete fertilzer should be used; in case of leguminous crops, phosphorus and potassium are particularly desirable, with a small amount of nitrogen to insure the crop a good start (p. 521).

(4) *Inoculation of soil.*—For leguminous crops, especially when grown for the first time, it is often necessary to inoculate the soil for the special crop grown in order to promote the formation of root-nodules and absorption of atmospheric nitrogen (p. 223).

(5) *Relations to different soils.*—Light, sandy soils are generally most benefited by the use of green-crop manures, because they are usually poorer in plant-food, lacking in humus, porous, and unable to hold moisture sufficiently for production of good crops. Green crops should be used that will supply nitrogen, moisture and organic matter. The bacterial decomposition of organic matter is very rapid, owing to the porous condition and consequent supply of air, and in such soils the organic matter is used up rapidly. Therefore, green crops must be used more frequently and, in order to neutralize the acids formed by the abundant supplies of decomposing vegetable matter, calcium compounds must also be applied more abundantly. In growing green crops on light soils, one serious difficulty often encountered is the limited amount of moisture available for crop growth. In case of cover-crops, the preceding crop may take so much water from the soil as to prevent the germination of seed and thus make it difficult to start the green crop. Then, again, green crops may use up so much soil moisture for their growth that while the green crop grows well, the fol-

lowing crop may suffer from lack of moisture. The excessive drying out of a soil generally results also in extensive destruction of the soil bacteria that are necessary for the conversion of the decomposition of organic matter and the change of its nitrogen into available plant-food. It follows, therefore, that green crops should not be seeded in an excessively dry soil.

The incorporation of a large amount of organic matter in a light soil increases the porosity and therefore the rapidity of evaporation of water. Hence, care should be taken not to turn under too large an amount of vegetable matter at one time. In the case of very bulky crops, especially if the crop is so mature as to be somewhat dry, it is well to remove a considerable portion of the crop, turning under only stubble and roots. Excessive evaporation of water may be lessened in light soils after turning under a green crop by compacting the surface with a roller.



ROOTS OF COMMON RED CLOVER. KANSAS STATION.

While light soils are peculiarly benefited by a proper use of green-crop manures, heavier soils are also improved under many conditions. Some of the more striking differences we will briefly notice. Increase of water-holding power in heavy soils is less important than in light soils. Decomposition of green crops in heavy soils is slower, the organic matter lasts longer and green-crop manures are therefore needed less often. Loss of nitrate nitrogen in drainage water is smaller in case of heavy soils, and cover-crops do not therefore effect as much saving of nitrate in heavy soils as in light soils. Loss of nitrogen as free nitrogen, except in case of

water-logged soils, is of less frequent occurrence in heavy soils. Another point of difference is that in heavy soils spring growth is less rapid than in light soils, which must be taken into consideration in the selection of green crops. More care is required in selecting green-manure crops for heavy soils. The plowing under of green-manure should be less deep in heavy soils than in light soils, since too deep covering retards decomposition of the vegetable matter and promotes the accumulation of organic acids in the soil. The decomposition of green-manure may be hastened by spreading over the surface of the green crop 2 or 3 tons of partially decomposed farm manure an acre, just before plowing the crop under, thus inoculating the soil with vigorous bacteria that cause decomposition of organic matter.

Time of plowing green crops under.—The precise time of plowing a green crop under is of much importance and is dependent upon several conditions, among which are the season of growth, the condition and character of the soil, the degree of maturity of the green crop, as well as weather and seasonal conditions. Generally speaking, green crops should be plowed in when they are still green and full of moisture, since they then decay most quickly, especially in light soils. If a green crop is allowed to become so mature as to contain large amounts of dry, coarse and woody stems, decomposition takes place slowly and the material remains unchanged in the soil for a considerable period of time, resulting in drying out of the soil by increased evaporation caused by abnormal looseness of soil and, consequent upon this condition, extensive destruction of those soil bacteria that produce decomposition of organic matter. There is more danger of this condition in light than in heavy soils. A similar result may occur if a green crop is plowed under when a soil is dry. Best results can come only when there is enough moisture in the soil to insure prompt decomposi-

tion of vegetable matter. Slow decomposition with injurious results is likewise experienced when a large amount of green matter is plowed under in warm, dry weather, or when a hot dry spell follows the plowing in. On the other hand, when a green crop is turned under in late summer or fall, and cool, wet weather follows, slow decomposition with production of acidity may result. The

ROOTS OF COWPEAS, 65 DAYS AFTER PLANTING. KANSAS STATION.

ideal condition for rapid decomposition of green-crop manures, without loss of nitrogen, is abundance of moisture and heat. When fall-sown crops are to follow the green-crop manure, it is desirable to turn the green crop under 4 to 6 weeks before planting time, harrowing frequently or compacting the soil in some other way.

Crops to follow green-manure crops.—In general, it is well to follow green-manures with cultivated crops,

such as corn, potatoes, tobacco, cotton, etc. The cultivation of such crops produces conditions that favor the decomposition of the vegetable matter and the consequent increase of available plant-food. Rye and oats generally thrive on green-crop manures, while wheat and barley appear to give variable results, especially the first season after plowing under a green crop.

Effect on succeeding crops.—Numerous experiments with different green-crop manures on many crops, under a great variety of conditions of soil and climate, have demonstrated that when properly used, the succeeding crops are generally much increased. As illustrations of the results of some of these experiments, red-clover increased the yield of corn 20 bushels an acre, of oats 10 bushels or more, of potatoes over 30 bushels; cowpeas increased the yield of seed-cotton 700 pounds an acre, of oats 10 bushels, while cowpea stubble and roots increased the yield of sorghum 2 tons an acre and wheat 4 bushels for four years in succession; crimson clover increased the yield of potatoes 20 bushels an acre the first year and 27 bushels the second. It is noticeable that the effects of leguminous green-crop manures last through several seasons. There is, however, a possibility that some crops immediately following leguminous green manures may be unfavorably affected. For example, when a large amount of organic nitrogen is incorporated in the soil by a green crop followed by hot, moist weather, favoring rapid decomposition with formation of nitrate nitrogen, the crop may get too much available nitrogen for normal growth and develop too luxuriantly in stems and leaves, as in the case of excessive applications of farm manure; under these conditions the ripening of fruit is delayed, and there is generally a decreased yield; with grains like wheat and barley, the straw is excessive in growth, lodging easily, and the yield of grain is diminished.

CHAPTER XX

CALCIUM (LIME) COMPOUNDS AND OTHER INDIRECT FERTILIZERS

An indirect fertilizer (p. 239) is a material which favorably influences crop growth through its effect on the soil rather than through direct addition of plant-food. Such materials are known also as soil *stimulants, tonics,* and *amendments.* The action varies for different materials, each producing effects more or less specific.

In recent years the subject of indirect fertilizers has become one of increasing interest and importance. Their intelligent use is attended with very satisfactory results in crop growing, while a blind, indiscriminating use may work harm to soil and crops and loss to farmers. It is, therefore, desirable that the subject should be treated with a fair degree of fullness.

The materials which may act as indirect fertilizers will be considered under the following divisions: Calcium or lime compounds and miscellaneous materials.

CALCIUM OR LIME COMPOUNDS

The different calcium compounds to be considered are used as indirect fertilizers for the purpose of bringing about in soil, through the action of the calcium contained in them, chemical, physical and biological changes that are beneficial to plant growth. Calcium compounds are not often used for the sole purpose of supplying calcium directly as plant-food to crops. The operation of applying calcium compounds to soils is commonly called *liming.* We shall study calcium or lime compounds under the following heads:

1 Composition.

2. What calcium compounds do in soils.
3. The practical use of calcium compounds.

COMPOSITION OF CALCIUM OR LIME COMPOUNDS

The chemical element *calcium* (Ca) is the one common, characteristic constituent of all so-called lime compounds, in which we find calcium combined with one or more other chemical elements. We are to keep in mind that it is this

FIRST CROP OF CLOVER WHERE, BEFORE LIMING, IT COULD NOT BE GROWN. RHODE ISLAND STATION.

element *calcium* which does the desired work, whatever compound of calcium we apply as an indirect fertilizer. The different calcium compounds available for agricultural use as indirect fertilizers are the following: (1) Calcium oxide, (2) calcium hydroxide, (3) calcium carbonate, (4) gypsum or hydrated calcium sulphate. There are other materials containing calcium compounds, which are chiefly used, however, for the purpose of supplying plant-food

other than calcium, among which are ground phosphate rock or "floats" (p. 262), wood-ashes (p. 283) and basic-slag phosphate (p. 275), the composition of which we have already discussed.

Calcium oxide or lime.—The word *lime* is ordinarily used to designate a compound consisting, when pure, of calcium (71.4 per cent.) and oxygen (28.6 per cent.), a compound known in chemistry as *calcium oxide* (CaO). At one time it was erroneously supposed that calcium oxide (lime) was present in all the different compounds of calcium, and so all calcium compounds were called lime compounds. This inaccurate use has continued, especially in commercial practice.

Calcium oxide in impure forms, is known under several commercial names, such as *lime, quicklime, caustic lime, burnt lime, stone-lime, lump-lime, unslaked lime,* etc. The value of commercial lime depends, for many purposes, upon its freedom from impurities, that is, upon the amount of calcium oxide it contains.

Commercial lime is prepared by heating at a sufficiently high temperature any form of carbonate of lime (calcium carbonate), the carbon dioxide (carbonic acid) being driven off as a gas and calcium oxide remaining as a solid residue, as shown by the following chemical equation:

$$\underset{\substack{\text{Calcium}\\\text{carbonate}}}{\overset{100}{CaCO_3}} + \text{heat} = \underset{\substack{\text{Calcium}\\\text{oxide}}}{\overset{56}{CaO}} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{\overset{44}{CO_2}}$$

The materials most commonly used as a source of commercial lime are limestone, oyster shells and shell-marl. It is evident that the purity of a lime (the percentage of calcium oxide present) depends upon (1) the purity of the original carbonate material used, (2) the completeness of the burning, and (3) subsequent care in keeping dry. The impurities commonly found in commercial lime are compounds containing magnesium, silicon, iron and aluminum

The three most common forms of commercial lime are: (1) Stone-lime, (2) magnesium stone-lime, and (3) oyster-shell lime.

(1) *Stone-lime.*—This is the ordinary lump-lime commonly used by masons. It is prepared by burning limestone (calcium carbonate) of a good degree of purity and should contain 90 to 98 per cent. of calcium oxide. Commercial quicklime can also be obtained in coarsely pulverized or granulated form. This is much used in building. It is a convenient form to use on soils.

(2) *Magnesium stone-lime.*—This is prepared from limestone that contains more or less magnesium carbonate, the proportions varying greatly in different varieties. Commercial lime prepared from such material contains 55 to 85 per cent. of calcium oxide and 10 to 40 per cent. of magnesium oxide. The presence of magnesium compounds affects unfavorably the slaking properties of lime.

(3) *Oyster-shell lime.*—Oyster shells contain 90 to 95 per cent. of calcium carbonate and, when properly burned, produce a high-grade lime, containing from 85 to 95 per cent. of calcium oxide.

In addition to the preceding forms of commercial lime, two others of less importance may be mentioned, known as *gas-lime* and *calcium carbide waste.* Quicklime is used at gas-works to remove impurities from the gas and after being so used it is often sold to farmers. Gas-lime is not quicklime, since the calcium oxide is largely changed into other forms, such as hydroxide (slaked lime) and carbonate. In addition, there are the impurities absorbed from the gas, some of which are injurious to seeds, such as sulphides and sulphites. These are changed into the harmless form of sulphate (land-plaster) on exposure to the air. Gas-lime should, therefore, be allowed to lie exposed to the air before use or should be put into the soil some weeks or months before putting in a crop. The composition of gas-lime varies greatly. *Calcium carbide waste* is the solid residue formed in the manufacture of acetylene

gas from calcium carbide; it consists largely of a mixture of calcium carbonate and hydrate (slaked lime), the proportions depending upon the length of exposure to air. The material has the disadvantage of being wet and of holding some acetylene gas. It can be used in liming soils where its cost is slight, but in order to allow acetylene gas to escape it is well to expose it to the air for some weeks before applying to the soil or to apply to the soil a few weeks before putting in seeds, because acetylene gas is injurious to seeds.

Calcium hydroxide or slaked lime.—When calcium oxide or quicklime comes in contact with water, it undergoes the change known as *slaking* (or slacking) ; its calcium oxide (CaO) combines with water (H_2O) and is changed into a compound known chemically as *calcium hydroxide* (CaH_2O_2) or commercially as *slaked lime, water-slaked lime, caustic lime,* or *hydrated lime;* 100 pounds of calcium oxide combine with about 32 pounds of water and produce 132 pounds of calcium hydroxide (slaked lime), as shown by the following chemical equation:

$$\underset{\substack{\text{Calcium}\\\text{oxide}}}{\overset{56}{CaO}} + \underset{\text{Water}}{\overset{18}{H_2O}} = \underset{\substack{\text{Calcium}\\\text{hydroxide}}}{\overset{74}{CaH_2O_2}}$$

Slaked lime may be conveniently regarded, therefore, as quicklime diluted by combination with about one-third of its weight of water. Calcium hydroxide or pure slaked lime contains 24.3 per cent. of water and 75.7 per cent. of calcium oxide, which is equivalent to 54 per cent. of calcium. The chemical change that occurs when lime slakes or combines with water is accompanied by marked physical changes; the lime swells in bulk, crumbles to a fine powder and generates much heat. The rapidity with which commercial lime slakes depends upon the amount of water used and the composition of the quicklime. The use of too much water or the sudden chilling of partially slaked lime by cold water

results in the production of a coarse, granular lime in place of the desired form of fine powder. Commercial limes containing less than 10 per cent. of impurities slake more quickly than those containing larger amounts of impurities. Magnesium stone-limes slake imperfectly.

One bushel of stone-lime of good quality, on slaking, increases in bulk to two or three bushels of slaked lime. The weight per bushel decreases roughly about one-half, for example, from 90 to 45 pounds. The bulk and weight of slaked lime depend upon the composition of the quicklime used, upon the amount of water added, and upon some special conditions of the slaking process.

Slaked lime suspended in or mixed with water to form a milky liquid, is known as *milk of lime.*

Slaked lime dissolved in water forms a clear solution known as *lime-water,* and is much used for medicinal purposes.

The calcium hydroxide of slaked lime easily absorbs carbon dioxide gas from the air and changes gradually into calcium carbonate. Just as commercial quicklime is impure calcium oxide, so commercial slaked lime is impure calcium hydroxide. Ordinary water-slaked lime is, therefore, a mixture of calcium hydroxide and calcium carbonate with such impurities as may have been present in the lime before slaking.

The slaking of lime also takes place when lime is exposed to the air, this process being known as *air-slaking.* When lumps of stone-lime stand exposed for some time, the outer layer gradually absorbs moisture from the air and goes through the process of slaking, forming a fine powder. In the air-slaking process, more or less calcium carbonate is also found. Hence, air-slaked lime usually contains larger amounts of carbonate and less of hydroxide than water-slaked lime. The rapidity with which limes air-slake depends upon different conditions. Dry, fine, air-slaked lime may at best contain as much as 75 per cent. of calcium oxide; but it varies much and is practically all carbonate if it has been exposed to air long.

Calcium carbonate is commonly known as ***carbonate of lime.*** In this form calcium oxide (CaO) is combined with carbon dioxide (CO_2), thus forming calcium carbonate ($CaCO_3$), which contains 56 per cent. of calcium oxide (equivalent to 40 per cent. of calcium) and 44 per cent. of carbon dioxide. This change is chemically shown as follows:

$$\underset{\substack{\text{Calcium}\\\text{oxide}}}{\overset{56}{CaO}} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{\overset{44}{CO_2}} = \underset{\substack{\text{Calcium}\\\text{carbonate}}}{\overset{100}{CaCO_3}}$$

However, the change never takes place in just this way, because the oxide (CaO) must be first changed into hydroxide (CaH_2O_2) before carbon dioxide combines. Hence, the actual change into carbonate is represented as follows:

$$(1) \quad \underset{\substack{\text{Calcium}\\\text{oxide}}}{CaO} + \underset{\text{Water}}{H_2O} = \underset{\substack{\text{Calcium}\\\text{hydroxide}}}{CaH_2O_2}$$

$$(2) \quad \underset{\substack{\text{Calcium}\\\text{hydroxide}}}{\overset{74}{CaH_2O_2}} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{\overset{44}{CO_2}} = \underset{\substack{\text{Calcium}\\\text{carbonate}}}{\overset{100}{CaCO_3}} + \underset{\text{Water}}{\overset{18}{H_2O}}$$

Just as we may regard slaked lime as calcium oxide diluted by combination with water, so we may regard calcium carbonate as calcium oxide or lime diluted by combination with carbon dioxide; 100 pounds of calcium oxide combine with about 80 pounds of carbon dioxide and produce 180 pounds of calcium carbonate. The carbonate is, therefore, a more dilute form of calcium than the oxide or hydroxide.

Limestone of high grade of purity, chalk and also many kinds of marble consist largely (95 to 98 per cent.) of calcium carbonate. Shells, coral rock, shell-marl, air-slaked lime, etc., contain calcium carbonate in varying proportions. Many limestone rocks contain varying amounts of magnesium carbonate. As previously stated, calcium carbonate is present in varying amounts in slaked lime, according to length of exposure to air; in ordinary *air-slaked lime* it is

safest to assume that the calcium is practically all in the form of carbonate.

Ground limestone is one form of carbonate of calcium that is applied to soils. Ground shell-marl is also used and, in its purest condition, may contain as much as 98 per cent. of calcium carbonate.

Calcium sulphate, hydrated (p. 55), known also as *gypsum, hydrated sulphate of lime, land-plaster,* etc., is a compound of calcium and sulphuric acid, with some water ($CaSO_4 2H_2O$, p. 55); 100 pounds of pure hydrated calcium sulphate contain about 32.5 pounds of calcium oxide (equivalent to 23 pounds of calcium), 46.5 pounds of sulphuric acid, and 21 pounds of water. When the water in gypsum is removed by heating the product is known as *plaster of paris.* We see that hydrated calcium sulphate or gypsum may be regarded as a more diluted form of calcium than either the hydroxide or carbonate. To carry as much calcium as is contained in 100 pounds of calcium oxide or pure lime requires about 310 pounds of gypsum.

Hydrated calcium sulphate in its commercial form of gypsum or land-plaster contains varying amounts of impurities, the presence of which decreases the percentage of calcium. Some land-plaster contains only 50 per cent. of pure sulphate of calcium, while the best contains over 95 per cent. It should, therefore, be purchased only on the basis of a guarantee. It should be used in finely ground condition. It is well to keep in mind that commercial acid phosphates (p. 271) contain hydrated calcium sulphate to the extent of several hundred pounds a ton. Generally speaking, farmers cannot afford to purchase gypsum as a source of calcium for use as an indirect fertilizer.

Comparative composition of calcium compounds.—It is a matter of practical importance to have a clear idea of the relative amounts of calcium contained in the principal compounds used to supply this constituent in agriculture, since it is the element calcium that these compounds are

used to furnish. A comparison in this respect is furnished by the following tabulated arrangement:

TABLE 38—AMOUNTS OF CALCIUM IN LIME COMPOUNDS

Form of lime compound	Calcium (Ca)	Calcium oxide (CaO) or lime	Water (H_2O)	Carbon dioxide (CO_2)	Sulphuric acid
	%	%	%	%	%
Calcium oxide, CaO (lime)	71.4	100.0	—	—	—
Calcium hydroxide, CaH_2O_2 (slaked lime)	54.0	75.7	24.3	—	—
Calcium carbonate, $CaCO_3$ (carbonate of lime)	40.0	56.0	—	44.0	—
Hydrated calcium sulphate, $CaSO_4.2H_2O$ (gypsum)	23.2	32.5	21.0	—	46.5

It is readily seen that the different compounds carry widely varying amounts of calcium. The equivalent amounts can be brought out more strikingly if we consider them on the basis of 100 pounds and of one ton.

To furnish the amount of calcium contained in 100 pounds of pure lime (CaO) requires 130 pounds of slaked lime, 180 pounds of carbonate, or 310 pounds of gypsum.

To furnish the amount of calcium contained in one ton (2,000 pounds) of pure lime (CaO) requires 2,600 pounds of slaked lime, 3,600 pounds of carbonate, or 6,200 pounds of gypsum.

In purchasing lime to apply on soils, it is of great practical importance to take into consideration these equivalent values.

Weight of a bushel of lime.—It is the custom in some places to sell lime by the bushel. *It should be purchased only by weight,* because the weight of a bushel varies greatly according to a variety of conditions, chief among which are porosity of the limestone burned and the conditions of burning. The average weight of a bushel (heaped measure) of stone-lime is given as 75 to 93 pounds, but it may vary from 60 to 120 pounds. Magnesium stone-lime usually runs

somewhat lower. Oyster-shell lime varies from 40 to 75 pounds a bushel and averages about 60.

Chemical changes and solubility of calcium compounds.—Some of the facts already stated about the changes that calcium compounds undergo need reviewing for the sake of emphasizing their importance and relations. Some additional facts regarding the solubility of calcium compounds deserve special mention at this point.

Necessity of lime for clover in some soils. The cylinders are 4 feet deep and are filled with equal amounts of the same soil; the grass and clover seed used in equal amounts in each cylinder and both fertilized alike. Larger growth due to lime. MASSACHUSETTS STATION.

(1) *Change of quicklime to slaked lime.*—Calcium oxide (CaO) or quicklime, as previously stated, combines with water (H_2O) to form calcium hydroxide (CaH_2O_2) or water-slaked lime; the attraction between quicklime and water is intensely strong. Quicklime put on or in soils is changed into slaked lime before chemical action on the soil constituents takes place. When, therefore, we speak of the

action of quicklime in soils, we usually mean the direct action of slaked lime formed from quicklime

(2) *Change of slaked lime to carbonate.*—Slaked lime or calcium hydroxide and carbon dioxide have very strong mutual attraction and combine to form the carbonate ($CaCO_3$). Perfectly dry quicklime is not acted upon by carbon dioxide; it must first be changed into hydroxide by combination with water. When quicklime *air-slakes,* the first action is combination with water to form hydroxide, after which carbon dioxide is taken from the air by the hydroxide and carbonate is formed. Whether applied to soils as quicklime or slaked lime, it is sooner or later changed into carbonate and does its principal work in the form of carbonate. In general, when we speak of the action of calcium compounds in soils, we usually mean the carbonate if we do not specify some other form.

(3) *Solubility of calcium compounds in water.*—The extent to which calcium compounds dissolve in water at ordinary temperatures is a matter of some practical importance in connection with soils. Quicklime does not dissolve as such in water but changes into the hydroxide, which dissolves at the rate of one part in about 600 to 800 parts of water, the solution being known as *lime-water;* and it is the calcium in this solution which combines so readily with carbon dioxide to form carbonate. Calcium carbonate dissolves only very slightly in pure water, but, when water is saturated with carbon dioxide, one part of carbonate dissolves in about 1,000 parts of carbonated water, less carbonate dissolving in water containing less carbon dioxide. One part of hydrated calcium sulphate or gypsum is soluble in 400 to 500 parts of water; it is more soluble in water containing in solution common salt or nitrate of soda

WHAT CALCIUM COMPOUNDS DO IN SOILS

When applied to soils judiciously, calcium compounds produce several specific effects, resulting in improvement of soils and increase of crops; however, injurious effects may

attend their use under some conditions, especially when certain forms are used in too large amounts. For convenience, the effects of calcium compounds may be grouped under three heads: (1) Chemical, (2) biological and (3) physical.

Chemical effects of calcium compounds.—The direct beneficial chemical effects of calcium compounds in soils may be divided into two general classes: (1st) They make available some insoluble forms of plant-food, especially in case of compounds containing potassium or phosphorus; and (2d) they change into harmless forms, or neutralize the injurious effects of, many compounds that interfere with the growth of plants.

(1) *Action on insoluble potassium compounds.*—One of the most important effects of calcium compounds is the conversion of insoluble into soluble forms of potassium; the soluble calcium takes the place of the potassium in the insoluble compounds and thus enables the potassium to form some new soluble form of combination. All of the conditions under which this change occurs are not completely understood and cases occur in which insoluble potassium compounds are not affected. The extent of this action is primarily dependent upon the amount and kind of potassium compounds contained in a soil. As would be expected, good results are more noticeable in clay soils, while sandy soils, which are often deficient in potassium compounds, are little affected. The effect of calcium in making potassium available is shown most prominently in the case of crops that require relatively large amounts of potassium, such as clover and other leguminous crops. It is probable that gypsum affects a soil more in this respect than in any other way.

(2) *Action on insoluble phosphates.*—Calcium compounds, especially the hydroxide and carbonate, change insoluble phosphates into forms that can be more readily utilized as plant-food. This action is based on the following chemical facts: The phosphates of iron and aluminum are more or less prevalent in soils; these compounds become soluble only with extreme slowness under ordinary condi-

tions. Calcium compounds, especially the hydroxide and carbonate, change these insoluble phosphates into tri-calcium phosphate, which is much more readily soluble in water containing carbon dioxide, as in case of ordinary soil water (p. 47). The application of the calcium compounds mentioned is, therefore, of marked value in this way in case of soils rich in iron and aluminum compounds but poor in calcium carbonate. The extent and value of the change involved in this action of certain calcium compounds have not been sufficiently appreciated. Most agricultural writers advise against the use of calcium compounds in soils where soluble calcium phosphate (superphosphate) is used, on the ground that the phosphoric acid will be rendered less efficient as plant-food. This objection has been greatly exaggerated, as experiments have shown.

(3) *Neutralization of acid soils.*—Soils which show acidity (p. 140), whether in the form of free acids ("sour" soils) or whether simply deficient in basic constituents (p. 141), are beneficially changed in character by the application of calcium compounds in the form of quicklime, slaked lime, or carbonate, but *not by sulphate* (gypsum or land-plaster).

(4) *Action on soil toxins.*—In addition to specific acids, soils may contain compounds that act as poisons to plants. For example, magnesium compounds, when present in large proportions, may act in this way; and on some soils the application of magnesium compounds in magnesium limestone, kainite, etc., may work injury. This condition can be overcome by the use of sufficient amounts of calcium compounds. Other poisonous substances, in the form of acid organic compounds in soils, are derived from plants as products of the decay of organic matter in soils, or, possibly, in part, as excretions of plant-roots (p. 129). Their injurious effects are overcome or prevented by the presence of enough calcium hydroxide or carbonate in the soil. In some cases, injurious soluble salts in alkali soils are rendered less harmful by calcium compounds. The "black

alkali" in soils of arid regions, due largely to sodium carbonate, is changed by sulphate into (1) harmless calcium carbonate and (2) sulphate of soda, which is less poisonous to plants than is sodium carbonate.

(5) *Favorable to decomposition of organic matter.*—The decomposition of organic matter is favored by the presence of calcium compounds (p. 137).

(6) *Economy of plant-food.*—It has been demonstrated that in the presence of abundance of calcium carbonate, smaller percentages of nitrogen, phosphorus and potassium compounds are generally required for crop production than when calcium is deficient.

(7) *Effect of calcium sulphate on ammonium carbonate.* Ammonium carbonate easily escapes into the air, but in the presence of abundance of calcium sulphate (gypsum) it is changed into the stable form of ammonium sulphate, and the calcium becomes useful as carbonate Quicklime and slaked lime do not possess this property, but, on the contrary, change all ammonia compounds into gaseous, free ammonia. Calcium carbonate does not have this unfavorable effect under agricultural conditions.

(8) *Harmful chemical effects of calcium compounds.*—The chemical effects thus far mentioned are for the most part beneficial, but injurious results, causing loss of plant-food or resulting in special unfavorable conditions, may attend the injudicious use of calcium compounds under some circumstances.

(a) Destruction of organic matter: The use of much quicklime or freshly slaked lime on soils greatly hastens the decomposition of organic matter. The danger is greater on sandy soils and on soils containing only small amounts of decaying organic matter (p. 136).

(b) Loss of nitrates: The formation of nitrates may be so hastened by calcium compounds, especially the caustic forms, as to furnish nitrates more rapidly or more abundantly than crops can use. Under such conditions nitrates are liable to be lost by passing into the drainage water.

(c) Acidity of soils increased by sulphate: The extensive use of calcium sulphate (land-plaster) may result in making a soil acid. The calcium of this compound is removed from the soil, the sulphuric acid being left behind to combine with some basic material, and if it continues to accumulate, it will obviously, in the course of time, be present in sufficient quantities to contribute very appreciably to the acidity of the soil. It must be emphasized, therefore, that *land-plaster never neutralizes soil acidity, but helps to make a neutral soil acid.* It is safe advice to recommend that farmers never apply gypsum or land-plaster by itself directly to soils.

Biological effects of calcium compounds.—In general, calcium compounds tend (1st) to make soil conditions favorable for the growth of many crops and for certain important soil organisms, and (2d) to prevent some kinds of plant disease.

(1) *Relation of calcium compounds in soils to kind of plant growth.*—The influence of calcium compounds in soils is shown by the character of growth of native trees and other plants. For example, chestnut trees show preference for soils not rich in calcium compounds, and likewise rhododendron and arbutus; leguminous crops, like clover, alfalfa, etc., and other desirable crops thrive best only on soils well supplied with calcium carbonate. Many weeds, which, like sorrel, flourish in acid soils, are discouraged in the presence of calcium carbonate.

(2) *Relation of calcium compounds to soil organisms.*—Calcium compounds, especially the hydroxide and carbonate, are closely associated with the favorable action of certain important soil organisms, which cannot be active in the presence of acids. The effects may be grouped under four general divisions: (a) Promotion of the decomposition of organic matter; (b) making conditions favorable for nitrification; (c) providing essential conditions for the growth of nitrogen-gathering organisms associated with leguminous plants; and (d) favoring the growth of those soil organisms

that utilize atmospheric nitrogen independently of other plants (p. 214).

(3) *Calcium compounds in relation to some plant diseases.* Calcium compounds are specific as a preventive of the disease known as club-root or finger-and-toe disease found in cabbage, turnips and similar crops, this disease occurring only in acid soils.

(4) *Harmful biological effects of calcium compounds.*— A strongly alkaline condition of soil, caused by the use of

INFLUENCE OF LIME

Portion of field on left, where crop is good, treated with lime and alfalfa soil.

Portion of field on right, where crop is poor, treated with Farmogerm but no lime. NEW JERSEY STATION.

too much caustic lime (quicklime or slaked lime), is apt to affect injuriously for a while bacterial and other processes, while excess of calcium sulphate causes unfavorable conditions by producing soil acidity. These effects may be specified more fully, as follows:

(a) Injury to nitrifying and decay organisms. A strongly alkaline condition of soil causes suspension of the normal processes of decomposition and nitrification. After a time,

when the caustic calcium is changed into carbonate, normal biological activities are resumed.

(b) Production of potato-scab. The application of calcium compounds in amounts sufficient to make a soil neutral or alkaline usually favors the disease known as potato-scab.

(c) Unfavorable action on crops. Some crops, like watermelon, cranberry, serradella, blue lupine, etc., give best results on very acid soils and are unfavorably affected by any considerable amount of calcium compounds.

Physical effects of calcium compounds.—The chemical changes produced in soil by calcium compounds are accompanied by marked physical changes.

(1) *Beneficial effects.*—Clay soils are made less sticky, more crumbly and more easily cultivated; water passes through them more readily as the result of increased porosity, and such soils furnish more congenial conditions, in general, for the growth of plant-roots. When used on some sandy soils, in small amounts, preferably in the form of carbonate, calcium tends to act like a cement in holding soil particles together, thus enabling the soil to hold water more tenaciously.

(2) *Harmful effects.*—The most common harm done soils by application of calcium compounds is related to their structure. Certain sandy and gravelly soils are made too open and are, therefore, injured by large application of calcium compounds, especially in the caustic forms. Muck and peat soils may be injured when a calcium compound is applied in a thin, superficial layer; the surface humus is more quickly used up and the result is a tendency to cause quick injury by drouth due to lack of water-holding power. To prevent this, the calcium compound should be worked more deeply into the soil.

PRACTICAL USE OF CALCIUM COMPOUNDS

Having learned the composition of different calcium compounds that are available for agricultural use as indirect

fertilizers and having stated their effects when applied to soils, we now come to a consideration of some of the more important points connected with the practical use of these compounds, and we shall treat this portion of our subject under the following divisions: (1) How to learn if a soil needs calcium, (2) how much and how often to apply, (3) at what time to apply, (4) what forms to use, (5) how to apply, (6) commercial classification of calcium compounds for agricultural purposes.

Beets grown on acid soil. The lot to the left on a plot to which lime was added, while that on the right was unlimed. RHODE ISLAND STATION.

How to learn if soils need calcium compounds.—Three methods can be used to ascertain if a soil is deficient in calcium carbonate, two chemical, one agricultural: (1) Litmus-paper test for acidity, (2) the dilute ammonia test for soluble organic matter, and (3) the growing of some crop that responds favorably to calcium carbonate.

(1) *Litmus-test for acidity.*—This test is described in full on page 142.

(2) *Dilute ammonia test.*—This test is described on page 127.

(3) *Growing of crops responsive to calcium carbonate.* The foregoing tests have the advantage of rapidity and simplicity and, when both used on the same soil, they may give reliable indications, but there are cases in which the results may leave one in doubt or prove misleading. Though requiring time and care, the most reliable test is to raise on the soil some crop that requires calcium carbonate in generous amount, such as red clover or beets. This test is made by growing the crop on small portions of an acre,

Effect of liming acid soils on growth of clover. The large pile on the left was grown on the limed plot, the very small pile next to it being weeds. The second pile from the right shows the clover, and the pile on the extreme right the weeds from a plot of the same area which received no lime. RHODE ISLAND STATION.

where the soil is uniform, one portion receiving some calcium compound like slaked lime or the carbonate and the other portion receiving none. In other respects the two portions of soil are treated alike; it is well to supply both with plant-food. In the case of red clover, the need of calcium carbonate is usually indicated when the crop after starting vigorously in the spring appears later to stand still in growth and finally disappears in part or wholly. Beets make poor growth on soils deficient in calcium carbonate.

It has also been frequently noticed that horse-sorrel and some other weeds make vigorous growth on soils deficient in calcium carbonate, though such growth does not always show calcium carbonate deficiency.

Amount and frequency of application.—The amount of calcium compounds to apply is largely governed by three factors: (1) The character of the soil, (2) the kind of crops grown and (3) the form of calcium used, but the general rule may be followed in nearly all cases of making applications in smaller quantities at more frequent intervals rather than large amounts once in several years.

(1) *Character of soil.*—On poor soils and in case of light, dry soils, the amount of calcium compounds applied should be comparatively small, varying from 500 to 1,500 pounds of quicklime an acre (equivalent to about 700 to 2,000 pounds of slaked lime and 900 to 2,700 pounds of carbonate). On heavy clay soils and on soils containing large amounts of decaying, acid, organic material, the application may vary from 1 000 to 4,000 pounds of quicklime an acre (equivalent to about 1,300 to 5,000 pounds of slaked lime and 1,800 to 7,000 pounds of carbonate), according to frequency of application, degree of soil acidity, etc. Soils rich in organic matter can utilize calcium compounds, when used in large amounts, more fully and with less danger of injury to soil or crops than soils that are deficient in organic matter.

In rotations lasting 5 or 6 years, one liming will suffice under usual conditions, and is preferably done at the time when the largest amount of organic matter is in the soil, as for example when a green crop or sod is plowed under In general we cannot emphasize too strongly the importance of supplying the soil with abundance of vegetable matter along with the use of calcium compounds.

(2) *Kind of crops grown.*—Some crops are little affected by the amount of calcium carbonate present within wide limits, and the amounts applied may therefore vary widely without materially affecting plant growth, other conditions being favorable. However, most of the crops commonly

grown are usually benefited by occasional use of calcium compounds in generous amount. Some few crops appear to be quite indifferent to the presence or absence of calcium carbonate in the soil, while a few plants are generally injured when much is present, such as watermelon, radish, potato, blue lupine, serradella, blackberry, raspberry and a few others of little importance. It should be stated that calcium carbonate may be applied in much larger amounts than quicklime or slaked lime without risk of injury to crops.

(3) *Form of calcium compounds used.*—In applying calcium compounds, we must keep in mind that the constituent of value supplied is *calcium.* When we put on a more dilute form, as the carbonate or the hydroxide (slaked lime), we must use more than when we apply the more concentrated form, quicklime or calcium oxide. From the data given on page 371, we can make the following simple rule to find out how to make the necessary calculations, assuming that the different forms are fairly alike in purity of composition: *To find out how much slaked lime is equal to a given amount of quicklime, multiply the number of pounds of quicklime by 1.3; to find out how much calcium carbonate is equal to a given amount of quicklime, multiply the number of pounds of quicklime by 1.8.*

When to apply calcium compounds.—Generally speaking, the matter of convenience may guide one as to what particular time of year to apply calcium compounds. Usually spring is more convenient than fall. The character of rotation will decide in many cases. In general the application should be made when it can be done to best advantage in the rotation, for example, before seeding to clover or in connection with the use of a green-crop manure. When practicable, autumn is the best time to apply the caustic forms, *quicklime* or *slaked lime,* on land to be used for spring crops as well as on permanent grass lands. The power of these compounds to injure seeds is gradually lost by lying in the soil, since they are changed into harmless carbonate. *Calcium carbonate can be applied at any time*

without risk of injuring seeds or crops. In case of fall seeding, quicklime or slaked lime can be scattered after plowing and then harrowed in very thoroughly. For many crops, the caustic forms of calcium may be applied in the spring with little risk of injury to seeds, provided it is worked into the soil completely and uniformly. In the case of very sour soils, application in spring is often very beneficial. So far as injury to seeds is concerned, gypsum can be applied at any time, but its use is not advised for direct application to soils.

When fertilizers containing ammonia compounds are to be applied to a soil receiving quicklime or slaked lime, it is well to apply the latter two weeks before the fertilizer in order to avoid risk of loss of ammonia. Stable manure should be very thoroughly incorporated in the soil when the caustic compounds of calcium are to be used; on soils possessing little power of retaining ammonia, like light, sandy soils, farm manure should not be applied until some weeks after caustic calcium compounds are used.

What form of calcium to use.—The particular calcium compound that should be used must be determined by the conditions attending each farmer, among which the following are the most important: (1) The cost of the calcium, (2) the character of the soil, (3) the kind of crop, (4) the rapidity of action desired, (5) fineness of division, and (6) convenience of handling.

(1) *Cost.*—When the material has to be freighted or drawn a long distance, quicklime in the form of commercial stone-lime or lump-lime should be found cheapest, since it is the most concentrated form, containing per 100 pounds more of the desired element, calcium, than any other form suited to agricultural use. In the table following we show at what price one should be able to purchase good quality of slaked lime, carbonate or limestone, and sulphate, when quicklime of good quality can be purchased at the prices given in the first column. The prices given assume high

grade of purity and equal fineness of division, which is not the actual case in carbonate and gypsum.

TABLE 39—COMPARISON OF PRICES FOR DIFFERENT CALCIUM COMPOUNDS

Cost of one ton of quicklime (CaO)	Equivalent prices at which should be purchased one ton of		
	Slaked lime CaH2O2	Carbonate ($CaCO_3$)	Gypsum ($CaSO_4.2H_2O$)
$8.00	$6.05	$4.50	$2.60
7.00	5.30	3.95	2.30
6.00	4.55	3.40	1.95
5.00	3.80	2.80	1.65
4.00	3.05	2.25	1.30
3.00	2.30	1.70	1.00

Stone-lime (quicklime) of high grade can, at the time of this writing, be purchased by the writer for about $5 a ton, delivered. To obtain calcium at the same cost per pound, it would be necessary to pay for slaked lime only $3.80 a ton, for carbonate $2.80 and for gypsum $1.65. As a matter of fact, none of these more dilute calcium compounds can be purchased in the writer's neighborhood at anything like these prices. For example, high-grade carbonate in the form of fine-ground marl, costs $4 to $5 a ton in addition to freight and drawing from railway station, making each pound of calcium cost nearly twice as much as in the quicklime.

There are in the market calcium-containing materials sold under various names, such as agricultural lime, prepared lime, hydrated lime, etc., some of which are slaked lime, some carbonate and some mixtures of the two. In some cases their coarseness greatly reduces their efficiency. They are usually sold at prices ranging from $8 to $10 a ton, much higher than the best grade of commercial lump-lime, on the basis of unjustifiably extravagant claims for peculiar virtues and superior merits. Farmers are strongly advised not to purchase these much-advertised materials, because they will always be found needlessly expensive. Some of these prepa-

rations have the advantage over commercial lump-lime in that they can be used without slaking, but under the circumstances this convenience costs too much. The cost of gypsum is prohibitive, and when we consider its serious limitations and few advantages, we can hardly regard it as a material that can be profitably used except, perhaps, for direct application to stable manure (p. 317).

(2) *Character of soil.*—On light, sandy or very porous soils and on any soils low in amount of organic matter, application of caustic forms of calcium compounds tends to hasten the decomposition of organic matter, unless used in amounts of less than 1,000 pounds an acre. It is safer, therefore, to use on such soils the carbonate which can be applied in large amounts without risk of injury. On heavy, clay soils and on soils rich in organic matter, caustic forms of calcium can be used in large amounts (1 to 2 tons of quicklime) without danger of decomposing humus too rapidly. The effect that quicklime and slaked lime have on organic matter should always be met by keeping an abundant supply of vegetable matter in the soil by means either of farm manure or of green-crop manures. On some soils that contain large amounts of magnesium compounds, it is desirable to avoid the use of lime rich in such compounds. However, on most soils, no trouble occurs from the presence of such compounds in the material used for liming.

(3) *Kind of crop.*—In the case of crops which are so sensitive to an alkaline condition of soil as to be injured, the use of carbonate is preferable. For crops that flourish best in neutral or slightly alkaline condition of soil, quicklime or slaked lime can be used with the precaution of avoiding application of excessive amounts (p. 382).

(4) *Rapidity of action.*—Quicklime is changed into slaked lime before it becomes chemically active under ordinary soil conditions. Properly slaked, quicklime forms a finer powder than it is possible to obtain with ground limestone or marl; it can therefore be more thoroughly and uniformly distributed through the soil, a condition that enables

it to act more quickly. Moreover, freshly slaked lime consists mostly of calcium hydroxide, which is more soluble in water than the carbonate (p. 373), and the usual difference of solubility is made greater by the extreme fineness of the slaked lime. This solubility is an important factor when a freshly limed soil receives abundance of rain, because a considerable amount of hydroxide goes into solution and on this account is more quickly and uniformly distributed through the soil. Then, again, calcium hydroxide, on account of its somewhat greater solubility, is more active than the carbonate in producing chemical changes in the soil. It is true, of course, that the slaked lime changes completely into carbonate sooner or later, but some weeks are required to complete the change even under favorable conditions, and during the intermediate period, previous to complete change into carbonate, the slaked lime must be regarded as more active chemically than carbonate.

(5) *Fineness of division.*—This has been referred to in the preceding paragraph. Quicklime in the form of commercial lump-lime or stone-lime must be slaked in order to permit even distribution in the soil. In properly slaked lime we have as fine a powder as it is possible to get. Ground limestone and marl are not nearly as fine as well-slaked lime. For the more prompt action of ground limestone, not less than 75 per cent. should pass a sieve with 100 meshes to the linear inch. Where quick action is not desired, some have used with apparent success coarser limestone, 60 per cent. passing a 50-mesh sieve, but none coarser than required to pass a 10-mesh sieve. When it will answer the purpose, limestone coarsely ground has the advantage of costing less than that finely ground.

(6) *Convenience of handling.*—The slaking of lump-lime and the distribution of the slaked lime cause some inconvenience and unpleasantness in handling. This disagreeable feature can be avoided by mixing the slaked lime with earth before distributing or by the use of ground burned lime, which is used for building purposes, coming

into the market in granular condition, and which is sold at reasonable prices. This can be handled with comparatively little trouble because it is usually put up in tight bags and does not require slaking before application. Much of the disagreeableness of distributing fine, slaked lime can be avoided by using a lime-spreader. Ground limestone or marl is also convenient to handle and is less disagreeable than slaked lime.

How to apply calcium compounds to soils.—In applying calcium compounds to soils, three facts should be kept in mind: (1) The lime should be distributed for the most part in the upper layer of the soil, say within 3 or 4 inches

LIME DISTRIBUTER. OHIO STATION.

of the surface; (2) it should be distributed as uniformly and thoroughly as possible through the soil; (3) in case of quicklime, it should be put into the soil while mostly in the form of slaked lime or hydroxide and before being changed more than slightly into carbonate.

The most convenient form of lime to apply is probably the ground quicklime that is furnished for building purposes and which can usually be distributed with a fertilizer-drill. There are, however, special lime-spreaders which are more convenient.

Freshly burned lump-lime may be slaked in a large pile near the field and then distributed; but when one has no special means for distributing the slaked lime, it is more convenient and comfortable under ordinary conditions to distribute the lump-lime in small piles over the field after the land is prepared for a crop. A little water (equal to about one-third the weight of the lime or about 4 gallons of water for one bushel of lime), is slowly poured on each heap and the lime covered with fine earth. To secure the finest powder possible, the slaking should not take place too rapidly; the use of too much water should be avoided. When thoroughly slaked, the powder is mixed with more fine earth to make it less disagreeable to handle and distributed with a shovel as evenly as possible, after which it is promptly harrowed into the soil very thoroughly. The size and frequency of the heaps of lime may be regulated by remembering that 20-pound heaps placed 20 feet apart make about one ton to the acre; or 25 heaps of quicklime with one bushel in each, make about one ton. After being spread, slaked lime should not be allowed to lie upon the surface overnight or during showers, owing to its tendency to cake and form lumps or crust, thus changing it from a fine powder into coarse particles or lumps.

Air-slaking is not advised, because it takes too long and the product is more largely carbonate than slaked lime proper.

Commercial classification of agricultural calcium compounds.—The importance of calcium compounds in relation to agriculture is shown by the action taken in adopting certain standards to be used as a basis in purchasing such materials. The following schedule (with some explanatory modifications) was adopted in 1909 by agreement between the directors of the New England and New Jersey agricultural stations and a special committee of the National Lime Manufacturers' Association:

- **Commercial lime compounds**
  - (1) High calcium
    - (1) Hydrate (Slaked lime, calcium hydroxide, CaH_2O_2)
      - (1) Spraying — Must contain 93% combined oxide and hydrate and all pass a standard 100-mesh sieve
      - (2) Land — Must contain not less than 90% combined oxide, hydrate and carbonate, of which not over 25% shall be carbonate
    - (2) Caustic (Quicklime, Calcium oxide CaO)
      - (1) Lump
      - (2) Fine
      - (3) Ground
      - Must contain 90% combined oxide and carbonate of which not more than 10% shall be carbonate, excepting ground, which may be 20% carbonate
  - (2) Dolomitic or high magnesium
    - (3) Ground limestone ($CaCO_3$) — Must contain 90% combined carbonates and pass 50-mesh sieve
    - (4) Kiln-slaked — Not guaranteed, contains core, ashes, and refuse

All shipments, except *kiln-slaked,* to be accompanied by a statement showing: (1) Proper class names and (2) guaranteed analysis, in which the respective percentages of calcium and magnesium oxides are given. Package shipments to show class and analysis on each package. Bulk shipments to have class and analysis statement attached either to invoice or inner side of car. All lime to be sold by cwt. or ton. Analyses to be those at kiln and guaranteed.

MISCELLANEOUS MATERIALS USED AS INDIRECT FERTILIZERS

In addition to calcium compounds and green-manure crops, many materials have been used as indirect fertilizers, some of undoubted value under special conditions and others of doubtful value or capable of positive harm. It is not desirable that we should discuss all these different materials, but we will select for brief notice a few about which there is occasional inquiry for information. The materials

to be discussed are the following: (1) Muck, peat, etc., (2) common salt, (3) magnesium compounds, (4) sulphate of iron, (5) soot, (6) coal ashes.

Muck, peat, etc.—The properties and composition of these materials have been already considered (p. 123). Their chief function as indirect fertilizers is due to their organic matter. The nitrogen they contain is slowly available. The effect of these materials is mainly physical, lightening clay soils and making them more porous, while rendering sandy soils more compact and more tenacious in holding water. In order to produce much effect on soils large amounts of muck or peat need to be added, 20 to 40 tons or more. Muck is more quickly effective and easier to incorporate into the soil evenly than peat. These materials cannot usually be economically employed unless close at hand and easy to handle. They should be removed and allowed to air-dry before distribution. Green crops will generally be found the most efficient source of organic matter. Muck and peat are best employed to mix with stable manure as an absorbent or as part of a compost mixture. While performing a useful service in saving urine in the stable, the insoluble nitrogen of the muck and similar materials is made available more quickly when mixed with stable manure than when the muck is put into the soil directly.

A good bed of muck or peat on a farm should be regarded as an important source of soil fertility, though largely indirect. It should be utilized systematically in one's plans for improving the soil. The value of these materials, when they are rightly utilized, can hardly be overestimated.

Common salt.—Common salt, consisting largely of sodium chloride (p. 58), has been used from time immemorial in agriculture, but its method of action has been little understood until recently and probably not fully even now. The form mostly used at present is known as "agricultural salt," which is refuse salt, too impure to utilize in regular commercial ways. The chief action of salt is believed to be that of changing the potassium from an insoluble to a

soluble form of combination. It also appears to economize the amount of potash used by crops in the case of root crops. Its extensive use on asparagus is of doubtful value aside from the setting free of potassium. In some cases experiments appear to show that salt renders insoluble phosphates soluble, while other experiments show the reverse. If used at all, it should be employed at first only experimentally on a small scale. The amount to use may vary from 200 to 600 pounds an acre. Larger applications at one time should be avoided

Another effect of salt is to hold soil moisture and regulate to some extent the upward movement of water. The extent of this action is of theoretical interest more than of practical importance. Such crops as tobacco, sugar-beets, potatoes are injured in quality by application of salt on account of the chlorine in it. Its use cannot ordinarily be advised unless it can be obtained for not more than $2 or $3 a ton. One-third of kainite is common salt.

Magnesium compounds.—Carbonate and sulphate of magnesium have been used to a limited extent as indirect fertilizers. Their action is like that of common salt and calcium compounds in changing unavailable into available potassium. Kainite is about one-sixth magnesium sulphate. The sulphate of potash and magnesium is about one-third magnesium sulphate. The use of magnesium sulphate or carbonate cannot be recommended except in those rare cases of soils that are deficient in magnesium.

Sulphate of iron.—Sulphate of iron is mentioned chiefly for the purpose of stating that its agricultural use has not been justified by reliable experimental evidence. Claims, based on inference rather than on the results of rigid experimental investigation, have been made to the effect that the bright coloring of apples and certain flowers is due to the presence of iron compounds. The use of sulphate of iron or other iron compounds for the sake of supplying iron to crops can, when viewed in the present state of our knowledge, be regarded as wasted effort. All agricultural soils

contain relatively immense amounts of iron compounds, when we consider the extremely minute amounts used by plants.

Soot.—While soot is to be regarded primarily as a nitrogenous fertilizer, containing on an average about 3 per cent. of nitrogen in the form of ammonia compounds, though varying all the way from 0.5 to 11 per cent., it also possesses important properties as an indirect fertilizer. On account of its dark color, it absorbs heat when sprinkled on the surface of soil and appreciably raises the temperature of the surface soil. Soot is very effective in lightening heavy soils. Another property, not a part of its action on soil, is its insecticidal value in case of slugs and small snails, which sometimes injure grain and other crops in their early stage of growth. Its use is of necessity limited on account of lack of supply. It is usually used as a top-dressing in spring on cereal crops.

Coal ashes.—Coal ashes possess marked value for their power to lighten heavy soils, and may be advantageously used for this purpose when near at hand and available without further cost than that of hauling to field.

PART III

Factors in the Selection of Fertilizing Materials

CHAPTER XXI

CONDITIONS OF EFFECTIVE USE OF FERTILIZERS

In using fertilizers, whether commercial or farm-produced, whether direct or indirect, it is highly desirable to know as far as possible something of the conditions under which they can be used with most effective results. It is necessary to discuss this subject as a preliminary to taking up two fundamental questions of practical importance that sooner or later come to every farmer: (1) Under what conditions is it necessary to use fertilizers? (2) What fertilizers will give greatest profit? These questions are asked most frequently with reference to commercial fertilizers and will be considered more particularly with reference to them, but they are pertinent also to all fertilizing materials.

With most farmers, the conditions determining the efficiency of fertilizers have been the last things to be thought of, if considered at all. Farmers who purchase fertilizers blindly, on the sole basis of the hope of obtaining larger crops and greater net income, inevitably run the risk of throwing away money by buying what may not give good commercial returns, due either to applying constituents not needed or to the application of needed materials under conditions so abnormal as not to permit of proper utilization by crops. Many millions of dollars annually have been and are being spent for fertilizers without any adequate return and therefore at a positive loss.

In Part I, we have studied the more prominent facts underlying our knowledge of plant nutrition, including the relation of plant-foods to soils. In presenting the

facts, we have made an effort to keep in mind that the effectiveness of plant-foods in relation to crop production, especially when applied in the form of purchased fertilizers, is unavoidably connected with and dependent upon numerous other factors. It is our purpose now to

Difference of yield due to seed. High and low yielding types of corn. OKLAHOMA STATION.

review and summarize the more important facts, preliminary to taking up a detailed study of the practical use of fertilizers in crop growing.

When considered in the most comprehensive way, several kinds of factors enter into the successful growing of crops, such as (1) the personal knowledge and ability of the grower himself, (2) the negative factors that appear in the form of insect pests, plant diseases, etc., (3) most important for our purpose, the natural factors that directly determine the conditions of plant growth,

and (4) artificial methods of control, including (a) tillage, (b) crop rotations and (c) fertilizers. We will briefly consider the direct natural factors as preliminary to a study of crop rotation and fertilizers. The subject of tillage has been already (p. 153) discussed as much as the limits of this book permit.

External natural factors of crop production.—The natural factors that directly control plant growth proper may be conveniently divided into two sets, those external to the soil and those directly centered in the soil itself.

In the first set of factors, we have: (1) Good seed, (2) sunshine (light and warmth), (3) physiological peculiarities of plant or crop, requiring adaptation of crops to conditions of climate, etc., and (4) sufficient rainfall favorably distributed in time.

Without detailed discussion, it is obvious that the use of fertilizers is vain when any of these factors is responsible for poor crops. In general, we assume, in the treatment of our subject, that such fundamental conditions are always carefully considered by farmers before they attempt to grow any particular crop, though there are probably many exceptional cases, especially when new crops or new varieties are being grown experimentally for the first time. It is obvious, also, that some of these conditions are not under our control and, when they are unfavorable, it is hopeless to work against them.

Good seed.—One of the conditions that can be controlled is that of seed, a fact that has been emphasized in recent years. It is probable that the important relation of good seed to successful crop production has never been so fully appreciated as at the present time. We will briefly mention some of the more important facts in this connection.

By careful selection and breeding, varieties of seed have been obtained that are especially adapted to cer-

tain climatic conditions, so that one variety will produce two or three times as large a crop as another, when both are grown under the same soil conditions. For example, the provincial department of agriculture has developed varieties of early maturing wheat well adapted to the conditions of the short hot summers of the Canadian Northwest. The Illinois experiment station has produced variations in corn such that one variety contains much more protein, while another contains much more oil. Similarly, beets grown from some varieties of seed contain less than 5 per cent. of sugar, while those grown from other selected varieties commonly contain 12 per cent. and sometimes over 16 per cent.

ENGLISH BEAN

Plants from heavy and light seed. *a*. Plant on the right from seed weighing .847 gram. *b*. Plant on the left from seed weighing .389 gram. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

It is well known that in different lots of the same variety of seed important differences are found. Generally speaking, seeds that are large, plump and well-ripened give better crop yields than small seed or those that are immature or shrunken. The importance of seed selection has been especially well illustrated in the case of corn growing, the yield having been greatly increased as the result of care and intelligence in this matter.

Purity of seed is another important condition. The necessity of freedom from weed seeds needs no discussion. Farmers should, in case of doubt, purchase only from reliable parties under a guarantee of purity and should have their seeds tested in respect to purity. This work of testing is generally performed gratuitously at

any of the agricultural colleges or experiment stations.

Soil factors of crop production.—The second set of natural factors that directly control crop yield are those directly centered in the soil itself, and are the ones which particularly call for our consideration. The conditions required in soils to promote the growth of crops are:

(1) Abundance of available plant-food.

(2) A suitable physical structure, (a) which combines mellowness and firmness, permitting plant-roots to extend their growth freely; (b) which enables the soil to receive water easily, distribute it uniformly, hold it with sufficient tenacity, and give it up as needed by plants; (c) which permits some circulation of air, furnishing needed supplies of oxygen; and (d) which makes the soil able to absorb heat and maintain a degree of warmth suited to plant growth.

(3) The presence of beneficial micro-organisms and conditions favorable to their growth.

(4) The absence of substances poisonous to plants, including acids, inorganic salts, and organic compounds.

A soil may contain an abundance of available plant-food and yet fail to grow satisfactory crops, if any serious defect exists in the soil structure or if poisonous substances are present. When it comes to the economical use of certain forms of plant-food supplies and the conversion of unavailable into available forms, then we must also take into consideration the presence of micro-organisms and the conditions affecting their existence and growth. We may briefly repeat here what has already been more fully stated in Part I, that the physical conditions most favorable to the growth of plant-roots are the precise conditions that are most favorable to the growth of desirable agricultural micro-organisms.

We have previously learned (p. 101) that the physical structure of a soil is largely governed by the texture

EXPERIMENT PLATS. NEW JERSEY STATION.

or fineness of particles and by the arrangement of the soil particles, the best structure being that known as the granular or crumbly structure. Soil structure is, to a large extent, under control and is influenced by tillage (p. 103), decaying organic matter (p. 135), drainage (p. 156), root growth (p. 103), soluble salts (p. 103), etc. Any one of the numerous conditions unfavorably affecting soil structure may, therefore, make useless the application of plant-food materials.

Selecting the special conditions or factors which most commonly affect the extent to which crops are influenced by plant-foods and which are largely controllable, we would emphasize the following as of special importance in this connection:

(1) Soil organic matter.

(2) Soil acidity.

(3) Soil structure.

(4) Soil moisture.

In order to have plant-food utilized by plants to best advantage, we must have, for the reasons presented in the earlier chapters of this book, an abundance of decaying organic matter (p. 117), a soil free from acid compounds in case of most crops (p. 140), an abundance of soil moisture (p. 145), and a soil structure that permits the best conditions for root growth (p. 92). It is obvious that these conditions are more or less interdependent, though, for the purpose of emphasis, we have arbitrarily separated them. One must first make sure that the soil conditions are satisfactory in these respects as a preliminary step in ascertaining when it is necessary to use fertilizers. If any defects in these respects exist, they must be corrected, and this may be done, according to the special demands peculiar to each case, by supplying organic matter through the agency of farm manure (p. 316) or of green crops (p. 348), draining

(p. 156), irrigating (p. 159), liming (p. 363), improved tillage (p. 153), etc.

Relation of soil conditions to available plant-food.— The fact cannot be too strongly emphasized that the conditions of the soil to which attention has been called in connection with efficiency of applied fertilizers are just the conditions that are most effective in changing the unavailable or slowly available forms of soil plant-food into readily available forms. The best methods of soil management have for one of their chief purposes the utilization of the slowly available plant-food supplies present in the soil, making them gradually available during the crop-growing season in amounts sufficient to meet the needs of crops.

With the foregoing statements in mind, it can readily be appreciated how hopeless it is to try to answer some of the questions asked by farmers, one of the most common of which is: "What fertilizer will give me the best results for this or that particular crop?" It is, of course, impossible to give any definite, reliable answer to such a general question, involving so many different factors, none of which is clearly known. As we have repeatedly pointed out, the composition, the physical properties and the biological conditions of the soil, the extent and manner in which it has been previously cropped, fertilized and managed, the kind of crop one wishes to grow, all of these conditions need to be known, and even then it will require some practical experimenting on the part of the individual farmer to determine what forms and amounts of fertilizers he can use most economically.

During the past generation our knowledge of the functions and proper use of fertilizers has been largely increased as the result of experimental investigation, and even more rapid advances are now being made; yet we must confess that with all these additions of knowledge and experience, there is yet no simple way of determin-

ing beyond doubt when and how best to use fertilizers in crop growing. The conditions involved are extremely complex and do not usually permit any reliable, short-cut methods of reaching satisfactory conclusions.

In selecting fertilizers for use, we need to consider numerous questions of fundamental importance, among which we mention the following:

1. Conditions under which fertilizers should be used.
2. The specific constituents of plant-food needed.
3. The amount of each fertilizing constituent needed.
4. The forms in which it is best to supply plant-food constituents.
5. Facts about commercial fertilizers.
6. Home-mixed fertilizers.
7. Methods and seasons of applying fertilizers.
8. Crop-rotation in relation to the use of fertilizers.
9. Plant-food mixtures for different crops.

CHAPTER XXII

CONDITIONS REQUIRING FERTILIZERS—PLANT-FOOD CONSTITUENTS NEEDED

In the case of fertile virgin soils, abundant crops are raised without application of any form of fertilizing material, direct or indirect. Under such a system of treatment, even the richest soils sooner or later begin to show decrease of crop yield. It is then that the farmer begins to make use of farm manure and other resources of the farm to check the decreasing crop yield. Assuming that this is all that is needed at first, there comes a time in most systems of farming when all the resources of the farm capable of furnishing fertilizing materials are insufficient to maintain the former yield of crops. Assuming that the conditions affecting the efficiency of plant-food materials do not require attention, the next step necessary to maintain crop yield is the use of purchased plant-foods or commercial fertilizers. Stated in a broad way, a farmer must resort to the use of commercial fertilizers when he has exhausted all of the resources of the farm in producing his own fertilizing materials and finds that the use of commercial fertilizers results in increased crops and profit. When, under conditions of good soil management, the farmer's crops cannot get from the soil during the growing season as much nitrogen or phosphorus or potassium as they need for profitable production, and when the resources of the farm in furnishing plant-food materials have been utilized to their fullest extent without maintaining desirable crop yield, then one may resort successfully to the use of commercial fertilizers. In order to make the use of purchased plant-food materials a paying operation, one must

secure an increase of crop more than sufficient to pay for the fertilizer used and for the cost of labor in applying it.

As we have stated in the preceding chapter, one must be sure that lack of crop yield is not due to some unfavorable soil condition other than deficient supply of plant-food, before resorting to the use of commercial fertilizers, if economy of production is to be realized.

It is, therefore, readily seen that it is not a simple matter to tell when one should use commercial fertilizers. But the general rule will be to use them when their application is attended with increased income due to larger crops. It is obvious that this condition can be ascertained only by actual trial or experiment, a subject which will be considered in detail later (p. 416).

There are indications of various kinds that may suggest the need of applying purchased plant-food materials, and we will consider these in connection with our discussion of what plant-food constituents are needed.

How to ascertain what specific plant-food constituents are needed.—When it has been settled that a soil needs the addition of purchased plant-foods in order to grow crops more successfully, the question at once presents itself as to what kinds of plant-food are required. Does nitrogen need to be supplied, or is it phosphorus that is needed, or is it potassium? How can we ascertain what kind of plant-food is required? Several methods have been employed, some of which are useful in the way of furnishing helpful suggestions, but there is in reality no simple method upon which we can rely for all soils and under all conditions. Experience and practical judgment often count for much but may lead one wholly astray. Among the ways of finding out what particular plant-food constituent or constituents a soil needs, we will consider the following: (1) Analysis of soils, (2) appearance of crops, (3) special character of certain

soils, (4) suggestions furnished by previous cropping, (5) fertilizer experiments.

Analysis of soil as indication of plant-food needs.—It was formerly thought that a chemical analysis of any soil would readily furnish information regarding the amounts of nitrogen, phosphorus and potassium, which would enable one to know whether any of these constituents was lacking and to what extent, if any, one needed

Experiments with rye, using cylinders set in soil. Soil house where crop samples are dried, ground and stored. NEW JERSEY STATION.

to add to the soil the deficient constituent or constituents in order to insure an abundant crop. It is not difficult for a trained analytical chemist to determine the amount of each plant-food constituent in a soil, showing the total amounts held as a store for the future, but such results furnish no information as to how much of these total amounts is immediately available for crop growth.

Usually, a soil analysis is made by treating a sample of soil with a dilute acid; it is supposed that the amounts of plant-food constituents thus dissolved approximate the proportions that are more readily available for the use of plants. When these results are compared with actual crop growths on the field from which the sample of soil analyzed is taken, wide discrepancies often occur. The actual value of soil analysis in determining positively and definitely the plant-food needs of a soil has been and is still a matter of dispute. All agree that the results of soil analysis are negatively helpful in enabling one to reach conclusions, when it is shown that the total amount of any plant-food constituent is present in very small amount or wholly absent. However, there appears to be no general agreement as to what shall be regarded as the lowest amount of any particular plant-food constituent calling for special addition to meet crop growths. For example, one investigator states that, in general, soils containing less than 0.20 per cent. of acid-soluble potassium (0.25 per cent. of potash) call for early application of potassium compounds. This figure may vary with certain soil conditions. Soil analysis is often found useful in careful investigations especially in connection with field experiments, but, as previously stated, the two methods do not necessarily furnish harmonious results. Studies have been carried on to learn what relations might exist between water-solutions of soils and available plant-food, but the results have not been sufficiently reliable as a guide to aid one in applying fertilizers.

Another consideration will illustrate how misleading the result of a soil analysis by itself may be. A soil may be shown by analysis to have large amounts of available plant-food constituents and yet fail to grow satisfactory crops owing to some defects in the physical condition

of the soil, such as have already been dwelt upon in the preceding chapter.

To point out one more defect in connection with soil analysis as a guide to follow in connection with the use of fertilizers, the methods of analysis have marked limitations in respect to accuracy and delicacy. To obtain a sample of soil that really represents a field is extremely difficult, at least in many cases. The amounts of plant-food constituents that one works with are often extremely minute. For example, in a soil containing 0.20 per cent. of phosphorus, two different analysts will usually obtain results several hundredths of one per cent. apart. Since each hundredth of a per cent. is equal to 250 or 300 pounds an acre, a comparatively slight difference of analysis, say 0.03 per cent., means a difference of 750 to 900 pounds an acre. To illustrate the limitations of soil analysis in delicacy, if we put on one acre of soil 1,000 pounds of sodium nitrate (containing 150 pounds of nitrogen), an abnormally large application, it will usually produce most marked effects upon plant growth, when other conditions are favorable; but this amount of nitrogen means only 0.005 per cent. of the acre soil, an amount too small to determine in a soil with reliable accuracy by chemical analysis. And yet much less than this amount of nitrogen will affect crop growth. However delicate may be the methods of chemical analysis, the methods of plants are still more sensitive, since plants are able to show differences in soil where chemical analysis cannot measure them.

Soil analysis is, however, an essential part of any complete soil investigation, and, taken in connection with other data, furnishes valuable information. In the case of a region where soils have been extensively studied, soil analysis may furnish desired information in the case of individual farms that partake of the general character of the region. But an ordinary soil analysis, taken by

itself, is generally found insufficient as a basis in deciding what kinds and amounts of plant-food to use for crops.

Appearance of crops as indication of needs of plant-food.—To one experienced in watching the behavior of crops, much may often be learned regarding the plant-food conditions by closely observing the appearance of the crops. The precaution should be given that this method is not an infallible one, because an abnormal condition of appearance caused by deficient plant-food supply may likewise be caused by some other condition not necessarily connected with the supply of plant-food in the soil.

(1) *Nitrogen.*—(a) Deficiency. When the physical condition of the soil is favorable and when there is abundance of rain and sunshine without excess, a pale-green or yellow color in plant leaves or stems, or a small growth of leaf or stalk, is commonly an indication of nitrogen starvation, due usually to an insufficient supply of available nitrogen. The same effects may be caused by some forms of plant disease or by some insect pests, due probably to inability of plants to use their nitrogen supply even when present in abundance. The yellow appearance of crops in time of drouth is largely due to the inability of the plants to obtain their needed plant-food supply because there is insufficient moisture to dissolve and carry the plant-food constituents or, in some cases, because the soil solution becomes so concentrated as to injure plant roots. In the case of heavy soils, a cold, wet spring delays nitrification (p. 204) to such an extent that the soil does not furnish available nitrogen rapidly enough to meet the demands of the young crop and this condition is shown by the unhealthy, pale appearance of the plants. A change to warm and less wet weather or an application of sodium nitrate under

such circumstances usually produces sudden and marked change in the color and growth of the crop.

(b) Abundance of nitrogen.—A bright, deep-green color, with a vigorous growth of leaves and stalks, is, in case of most crops, a sign that available nitrogen is not lacking, but does not necessarily indicate that more nitrogen could not be used to advantage.

(c) Excess of nitrogen.—An excessive growth of leaves and stalks, accompanied by an imperfect development of bud, flower or fruit, generally indicates too much nitrogen in relation to phosphorus and potassium. The application of large amounts of fresh farm manure furnishes relatively large quantities of urinary nitrogen, which, under favorable soil conditions of warmth, moisture, ventilation, etc., may be so rapidly changed into nitrate as to furnish the crop an excessive supply. This has been a common experience with farmers. The results have been manifested in the case of grain crops by large growth of straw and small yield of grain, the crop showing a tendency to "lodge" (p. 66); in the case of crops like potatoes, there is an enormous growth of tops with comparatively few and small tubers. Such excess of nitrogen has been reported also as the result of plowing under leguminous crops too frequently, but this is probably of somewhat rare occurrence. This condition can be remedied by avoiding large applications of nitrogen-containing materials or by accompanying such applications with addition to the soil of phosphorus or potassium compounds or both. As will be pointed out later (p. 618), there are some crops which require large amounts of nitrogen for best results in growth and quality, and the amounts which would injure cereal crops, for example, are not too much for the needs of such crops as celery, asparagus, lettuce, etc.

(2) *Phosphorus.*—When under favorable soil and climatic conditions grain crops mature early and furnish

smooth, plump, and heavy kernels, a good supply of available phosphorus in the soil is indicated. Slow-maturing grain crops, with light, shrunken kernels, is usually due to an excess of nitrogen in relation to phosphorus, as in case of fresh farm manure.

(3) *Potassium.*—When such crops as corn, cabbage, grass, potatoes, tomatoes, beets, etc., have a vigorous, strong, healthful growth, there cannot be a deficiency of potassium compounds in the soil. Another indication of the presence of abundance of potassium is the growth of fleshy fruits of fine flavor and texture. Deficiency of potassium is often indicated by weakness and brittleness in stalks and leaves.

As we have already stated, such special indications may often be most helpful, and the conditions of crops should be carefully studied with all the facts in mind. In interpreting such signs too narrowly, and without taking all conditions into consideration, such as season, diseases, insects, etc., there is always the danger of being misled at times. Then, too, unfavorable indications shown by crops may be due to conditions which are temporary and which will adjust themselves, as, for example, in case of unfavorable weather.

Plant-food needs in relation to character of soil.—In certain special kinds of soils, such as clay, sandy and peaty soils, the character of the soil often furnishes valuable information as to what kind of plant-food may be lacking.

(1) *Clay soils,* owing to their origin (p. 95), are usually well supplied with potassium compounds but are apt to be deficient in phosphorus and often in calcium compounds. Therefore, treatment of many clay soils with phosphorus will supply that element, while application of calcium compounds may be sufficient to insure a generous supply of potassium for crops.

Experiments with corn on peaty swamp-land, showing need of potassium. Upper view: Potassium on left with nitrogen and phosphorus on right. Lower view: Nitrogen and phosphorus on left with nitrogen and potassium on right. ILLINOIS STATION.

(2) *Sandy soils,* as might be anticipated from their origin (p. 94), are often lacking in an abundant supply of potassium and they often require phosphorus also; the same is true of many gravelly soils, owing to their liability to lose plant-food by leaching.

(3) *Peaty soils* are rich in nitrogen in forms not quickly available and are often deficient in potassium and phosphorus. Therefore, the application of potassium and phosphorus compounds to drained swamp-lands is usually attended with marked advantage in crop yield.

In the numerous mixed types of soils, where no one character is pre-eminent, these suggestions find no application, and most soils are of the mixed types.

Kind of plant-food suggested by previous cropping.— The growing of the same kind of crop continuously on the same land may be exhausting in regard to one or more elements of plant-food. For example, when wheat is grown year after year on the same soil, the available nitrogen and phosphorus are used in larger proportions than potassium. When such deficiency actually occurs, then application of nitrogen and phosphorus compounds is called for. On old wheat-growing soils, it is generally found true that special benefit comes from applying phosphorus compounds. The continuous growth of grass crops takes large amounts of potassium compared with phosphorus. Other explanations have been offered for the unfavorable effect of continuously growing the same kind of crop on the same soil. One is that there accumulate in the soil compounds that are poisonous to the crop thus grown (p. 128); these toxic substances are thought to be the products of decomposition of crop residues left in the soil or possibly to be excreted by the plant-roots. The beneficial use of fertilizers is attributed to their effect in changing the poisonous compounds to harmless or even beneficial ones. Decreased crop yield, as the result of continuous growing

of a single kind of crop, is, according to another explanation, due to the action of certain fungi (p. 230), whose presence in the soil is promoted by such a system of cropping.

Fertilizer experiments.—The most common method employed in soil investigations during the past to ascertain what constituents of plant-food a particular soil needs to produce increased crops of a given kind has been to apply different plant-food constituents to different portions of a soil and observe whether or not any increase of crop results. Theoretically, this is the simplest and most direct method and should give helpful results; and while it frequently does so, it does not always, and may in some cases, give results that are contradictory, meaningless or misleading. When such experiments are carried on for long periods of time in a systematic way by skilled investigators and the results checked by all possible precautions, useful results are obtained. Such experiments carried on for a single season may be wholly misleading, especially if some abnormal weather conditions happen to be present. Under ordinary conditions and in the hands of one willing to give the work reasonable attention, the method may be found reasonably helpful for the purpose in view.

Another method of soil-testing is to grow plants in boxes or pots filled with the soil to be experimented with, applying different fertilizers and combinations in different amounts. Under some circumstances helpful results are often obtained. A modification of this method is known as the "paraffin-basket" method of soil testing. Without going into the details of these different methods of pot experimenting, it is sufficient for our purpose to say that they are not suitable for use in the hands of farmers for the purpose of ascertaining with any satisfactory degree of certainty or accuracy the plant-food needs of a soil.

As a matter of information for anyone who desires to undertake field experiments, we will give in some detail the methods for such work.

(1) *Selection of land for field tests.*—The land selected for testing its plant-food needs should be in good condition in respect to tillage, drainage, etc. The character of the soil should be as nearly the same as possible throughout the test field. It is desirable also that the surface shall be quite level and uniform. The more worn-out soils are, the more readily they respond to experiments, and the more definite the results that may be expected.

(2) *Size of experimental plots.*—A convenient size of plot to use for a field test is one-twentieth of an acre, containing an area of 2,176 square feet. The length and breadth of the plots can be such as suits one's convenience, but it is suggested that each plot measure 8 rods long and 1 rod wide; another suggestion is 204 feet in length by 10 feet 8 inches in width. Between the plots there should be left unused strips 3 or 4 feet wide so as to avoid any possible mixing of the different plots.

(3) *Preparation of soil.*—Select a portion of the field that represents a fair average, which has been previously cropped and manured alike; prepare the soil as carefully as possible for the crop, then measure accurately and stake out into plots 204 feet long and 10 feet 8 inches wide, leaving between the plots strips 3 or 4 feet wide. Mark each plot by a number corresponding to the kind of fertilizer used, following a diagram previously laid out on paper.

(4) *Application of fertilizer.*—Accurately weigh and distribute each fertilizer evenly over its own plot, mixing it thoroughly with the soil and keeping the fertilizer from going outside of the plot. It is better to apply the fertilizer broadcast and before planting, if the crop is not a cultivable one. For cultivable crops, the fertilizer

may be applied after planting and worked in. On the basis of the amounts of fertilizer given below there will be one pound of fertilizer, or an even multiple of it, for each square rod of surface. In order to distribute the fertilizer more evenly it will be well to mix the fertilizer with two or three times its own weight of fine, dry, inert material, such as sifted coal ashes, sand, or dirt.

(5) *System in conducting fertilizer experiments.*—From beginning to end, the work must be done systematically, thoroughly and accurately, if beneficial results are to be expected. The harvested crop on each separate plot must be carefully weighed and a record kept of all results.

(6) *Plan of experiment.*—The diagram below represents an arrangement of plots, together with kinds and amounts of fertilizers to use. The particular crop with which to experiment may be left to the choice of the individual farmer, but it is preferably a crop which can be grown to advantage on his farm. For first trials, corn or potatoes or oats may be used, to be followed by such others as are usually raised on that particular farm. The work should be carried on for several seasons. It must be kept in mind that such experiments are more or less at the mercy of the weather, which may seriously interfere to destroy the value of the results. For example, an excessively wet or an excessively dry season will not lead to satisfactory conclusions. Reliable results can be obtained only by repetition if seasons are in any way abnormal. All the plots should receive the same amount and kind of cultivation. The same amount of seed of the same quality should be used; in a word, all conditions of treatment must be kept alike as nearly as possible, except for the one difference of condition connected with the fertilizer applied. In the plan below we give a larger number of plots than any one should attempt at the start. The first year's work may be well limited to not more than five or six plots.

Diagram of Field Experiments

	Kind of fertilizer	Amount of fertilizer
Plot No. 1	No fertilizer	
Plot No. 2	Sodium nitrate	8 pounds
Plot No. 3	Acid phosphate	16 pounds
Plot No. 4	Potassium chloride (Muriate of potash)	8 pounds
Plot No. 5	Air-slaked lime, or Ground limestone, or Slaked lime	100 pounds 100 " 75 "
Plot No. 6	Sodium nitrate Acid phosphate	8 pounds 16 "
Plot No. 7	Sodium nitrate Potassium chloride	8 pounds 8 "
Plot No. 8	Acid phosphate Potassium chloride	16 pounds 8 "
Plot No. 9	Sodium nitrate Acid phosphate Potassium chloride	8 pounds 16 " 8 "

	Kind of fertilizer	Amount of fertilizer
Plot No. 10	Stable manure.........................	1000 pounds
Plot No. 11	No fertilizer	

(7) *Interpretation of results.*—If plots No. 1 and No. 11 give generous crops and as good results in crop yield as any other, then the soil appears to be in good condition as regards its present supply of plant-food. If plot No. 2 gives increased yield as compared with others, the need of nitrogen is indicated. An increase of crop on plot No. 3 indicates need of available phosphorus, and increase on plot No. 4 shows apparent need of potassium. Increase on plot No. 5 may indicate acidity of soil, or the presence of unavailable potassium compounds in the soil, or, perhaps, lack of calcium as plant-food. Improved crops in case of plot No. 10, compared with the others, suggest that there is probable need of organic matter in the soil. If plot No. 6 shows no increase of crop, then it would appear as if nitrogen and phosphorus were not deficient. If plot No. 9 gives the best results, need of nitrogen, phosphorus and potassium is shown. However, the results may vary in such ways that it is difficult to reach satisfactory conclusions, especially where work is done for only one season.

It may be stated further that the amounts of plant-food materials indicated above are larger than will be used on many soils and crops. But when once it is found clearly that some particular element of plant-food increases the crop yield every time, then some additional trials can be made to ascertain the smallest amount of application that will give most economical results.

Amounts of plant-food constituents needed.—How can

we ascertain how much nitrogen or phosphorus or potassium it may be necessary to apply to a soil to insure available plant-food enough to produce a satisfactory crop? This matter of amounts of plant-food to apply is one of great complexity and no simple way is known to answer the question. If we could know how much available nitrogen, potassium and phosphorus could be furnished a given crop by the soil during the growing season, we could from data similar to those given in Table 21 (p. 177), estimate the amounts of these plant-food constituents that would be needed for a certain yield of the crop, and by comparing these figures, we could ascertain whether the soil supply would meet the demands of the crop.

The factors that largely determine the amounts of plant-food constituents needed are: (1) The amount of available plant-food present in the soil, (2) the amounts of plant-food constituents required by the crop grown, and (3) the special kind of farming practiced. We will briefly consider these points.

(1) *The amount of available plant-food in the soil.*—The method of experiment given above is essentially the only means we have at present for ascertaining whether or not there is in a soil enough available plant-food of any particular kind to grow a crop, and this method, as we have pointed out, is not free from difficulty for the average farmer and the results cannot always be relied upon implicitly. This information cannot be gained with certainty by chemical analysis. While field experiments in the hands of many farmers often prove disappointing for the reason that definite conclusions cannot be drawn, such experimental work cannot be recommended too highly for the general training and educational benefit it affords. This line of work, properly conducted, may furnish the progressive farmer information of the greatest practical and economic value, but it will also exert

a profound educational influence upon him, making him personally familiar with plant-food materials and their specific effects, causing him to take a deeper interest in the growing of crops and leading him to practice better methods.

(2) *The amounts of plant-food constituents required by crops.*—We have already (p. 175) shown that different crops

EFFECT OF FERTILIZERS ON WHEAT, INDICATING NEED OF AVAILABLE PHOSPHORUS IN SOIL. INDIANA STATION.

use different amounts of nitrogen, phosphorus and potassium. If we know approximately how much of each plant-food constituent an average yield of any particular crop will remove from the soil, then we have fairly definite knowledge of the amount of each that it will be necessary to have within reach of the plant-roots during the growing season of the crop. However, such figures do not in every case represent the quantities of plant-food removed from the soil. Thus, in the case of leguminous crops, a portion of the nitrogen is generally obtained from the air and for such crops less nitrogen need be applied than the composition of the plant indicates. While such figures are useful as valuable suggestions, we cannot rely upon them as strictly accurate guides in telling us how much nitrogen or phosphorus or potassium to furnish a crop.

(3) *The special kind of farming practiced.*—The amount of plant-foods required for the economical growing of crops must depend to some extent upon the specific character and methods of farming employed. In the case of market-garden crops, where it is desired to secure maximum crops at the earliest possible time of season, it is the practice to apply amounts of fertilizers that would be regarded as wastefully excessive in general farm practice. Again, the farmer who utilizes an intelligent form of crop-rotation can raise crops with less expenditure for fertilizers than can the one who does not use a desirable system of rotation, as we shall point out later more in detail (p. 498).

From what has preceded, it becomes clear that we have no reliable method for determining accurately beyond question the plant-food needs of soils. The application of fertilizers in the growing of crops is still, and will probably always remain, more or less largely empirical, resting on experience and observation. The same is true of medical practice. Certain facts are known. Certain substances are

known to produce certain effects, under given conditions, but how those effects are produced is largely a matter of conjecture. The matter of soil fertilization is really more than the feeding of crops, since other conditions affect plant growth. When we apply plant-foods to soils, we not only place the material within reach of the grow-

Testing plant-food needs of virgin soil. The need of available nitrogen is shown by 2, 5, 6 and 8. IDAHO STATION.

ing plant, but the presence of the added material in the soil usually produces modifications of a physical, chemical or biological character in the soil itself and these modifications influence plant growth to an extent we cannot easily measure. It is this multiplicity of effects produced by a fertilizer that often makes difficult the correct interpretation of soil experiments.

While we cannot tell with any degree of accuracy in each special case how much plant-food to apply to a soil for best results, we are not left in hopeless confusion when it comes to the practical growing of crops. We know many facts of importance and we have the results of long-continued experience and observation, affording a basis for agricultural practice. While specific rules cannot be given that will be of general value, we can study the facts that have been accumulated and use them as suggestions for application to individual cases.

The remainder of this book will be largely devoted to stating facts of practical importance in addition to those previously presented, and to making specific suggestions which can be adapted and modified for use in individual cases.

CHAPTER XXIII

FACTORS IN SELECTION OF PLANT-FOOD MATERIALS

We have seen in Part II that we can obtain nitrogen, phosphorus and potassium, each in several different forms, such, for example, in case of nitrogen, as sodium nitrate, ammonium sulphate, calcium cyanamid, dried blood, cotton-seed-meal, etc. When we come to make use of fertilizing materials as sources of plant-food, we must decide which specific forms we shall purchase. What principles are there to guide us in making the best choice, all things considered? We can be guided by:

1. Availability of plant-food.
2. Effect upon soil.
3. Adaptation to crops.
4. Comparative cost.

AVAILABILITY OF DIFFERENT FORMS OF PLANT-FOOD

As a rule, commercial fertilizers are used for their effect upon crops during the single season immediately following application. The general practice among farmers is to give to each crop by itself the plant-food supplies which they think may be needed, and to avoid furnishing any year's crop with more material than it can use to best advantage. This is especially true of those who do not own the farms that they work and who plan each year's work by itself without reference to the future. Under such circumstances a farmer desires to use those forms of fertilizing materials which will be taken up most quickly and completely by crops in a single season. On the other hand, the farmer who owns his land frequently desires to use materials the plant-food of which

will be utilized gradually by crops and furnish a continuous supply through several successive seasons. For some crops it is a convenience and an advantage to use slowly acting forms of fertilizers. It will thus be seen that if one desires a fertilizer which will act at once and be largely used by the immediate crop, then he will need to purchase his plant-food in forms different from those used by the man who desires longer-continued action, extending through several seasons.

We will now consider the relative rapidity with which different forms of nitrogen, phosphorus and potassium are available for the use of plants, keeping in mind that plants use only those soil materials that are presented to them dissolved in the soil water.

Availability of different forms of nitrogen.—We have discussed in other pages the composition and general properties of the nitrogen-containing materials used as sources of plant-food (pp. 244-260). We will now consider them particularly with reference to the quickness with which plants can use their nitrogen when it is placed within reach of growing roots.

(1) *Nitrate nitrogen* (sodium nitrate, or nitrate of soda, calcium or lime nitrate, potassium nitrate, etc.) is easily soluble in water and its nitrogen is directly taken into plants (p. 171) and used. One part of sodium nitrate dissolves in only one part of water under ordinary conditions; that is equal to saying that one pound of sodium nitrate is completely dissolved in only one pint of pure water. The ease with which it dissolves enables it, in the presence of soil moisture, to be distributed quickly through the soil and reach the plant-roots. Therefore, on account of its ease of solution and owing to the fact that the solution can be directly absorbed and used at once by plants, nitrate is the most easily available form of nitrogen that we can furnish plants. Under favorable conditions, the effect of applying sodium or calcium nitrate to soils can be observed in the appearance of plants in one or two days. The extremely easy solubility

of sodium nitrate in water is a distinct advantage in respect to its availability, but is a disadvantage under conditions where a large amount of rainfall dissolves and carries it down into the soil below the reach of plant roots, with liability of loss in the drainage water, as already stated (p. 186). Nitrates should, on this account, be applied only in moderate amounts at a time, and preferably when crops are growing on the soil. On account of its rapid action on plant growth, nitrates are extensively used by market-gardeners and in forcing-house operations. On account of its easy solubility and

EXPERIMENT CEREAL PLATS. TENNESSEE STATION.

rapid action, nitrates are of special value as top-dressing in early spring on meadow-lands and on small grains before nitrification has begun and when soil nitrates are usually at their lowest.

(2) *Ammonia nitrogen in ammonium sulphate* (p. 41), ammonium carbonate and ammonium compounds in general follow nitrate nitrogen in point of availability as plant-food. The compound most commonly occurring in commercial fertilizers, ammonium sulphate, is easily soluble in water, about as much so as sodium nitrate (p. 40), and has, therefore,

the advantage of quick distribution in the soil, bringing it into the neighborhood of plant roots. It is claimed that many plants can absorb and directly use ammonia nitrogen just as they do nitrate; but to whatever extent this may be true, ammonia nitrogen is changed in the soil quite rapidly into nitrate (pp. 203-210) and under favorable conditions the ammonia is largely changed into nitrate before it reaches the plant. Ammonium compounds are not leached from soils as readily as nitrates (p. 186) and are therefore apt to give better results in wet seasons. The action of the ammonia nitrogen is somewhat more gradual and lasts longer than that of nitrate and is, therefore, preferred when the effect of the plant-food is to be extended through a longer period of crop growth.

(3) *Cyanamid nitrogen* (p. 247) in calcium cyanamid (lime-nitrogen) has been shown to have about the same degree of availability when compared for a growing season as that shown by ammonia nitrogen. This would be expected from the fact that, after cyanamid is applied to soils, its nitrogen changes into ammonia. Calcium cyanamid itself is not used as food by plants, but must decompose first into ammonia and then change to nitrate. It is noticeable that cyanamid is put on the market mixed with some nitrate, evidently with the purpose of furnishing some quickly available nitrogen, which can act while the cyanamid is becoming available, that is, changing first into ammonia, and then into nitrate.

(4) *Ammonium nitrate* (p. 251) combines the properties of both the nitrate and the ammonia nitrogen, the quickness of one and the moderation of the other.

(5) *Organic nitrogen* includes the various complex organic animal and vegetable materials containing nitrogen as a prominent constituent (p. 39). None of these materials is readily soluble in water and none is in condition for immediate use by plants. As we have explained (pp. 203-210), they first undergo bacterial decomposition, changing through a series of complex compounds into simpler forms,

and finally the organic nitrogen is changed to ammonia, and this in turn, by the nitrification process, into nitrate nitrogen. We thus see that the availability of organic nitrogen depends upon the rapidity with which it undergoes bacterial decomposition, and this in turn depends upon (1) the source of the organic nitrogen, (2) the fineness of division of the organic material, and (3) the soil conditions that affect bacterial decomposition, such as the presence of the right kinds of bacteria, proper degree of warmth, moisture, air supply, calcium carbonate, etc. (p. 193). It is obvious that no form of commercial organic nitrogen is as quickly available as either nitrate or ammonia nitrogen.

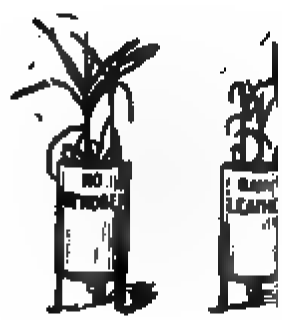
Generally speaking, the better forms of organic nitrogen can be used to advantage on crops whose period of growth is prolonged during the season, since they furnish a gradual supply of nitrate nitrogen as they undergo decomposition and nitrification. It is generally a wise plan to use in fertilizers some nitrate nitrogen for the immediate use of the young plants and furnish the remainder in the form of organic nitrogen, which becomes available after the nitrate is used.

Of the different materials containing organic nitrogen, *dried blood* (p. 254) becomes most quickly available. Of nearly equal value to blood in availability are finely ground *fish, cottonseed-meal,* and *castor-pomace.* Acidulated fish is somewhat more available than untreated fish. *Tankage,* on account of its variable composition and fineness, varies in availability, but may be generally regarded as considerably slower than dried blood. The availability of the organic nitrogen in *bone* varies greatly, depending on the fineness and previous treatment. In raw, coarse bone, the nitrogen is very slow in becoming available. The removal of fat by steaming or boiling makes the nitrogen more available for two reasons: In the first place, the presence of the fat interferes with the decomposition of the organic nitrogen, and, in the second place, the bone can be very much more finely ground after removal of fat. *Horn* and *hoof*

meal (p. 257), when very fine, appear to undergo decomposition about as rapidly as ground fish. Their availability can be increased by treatment with sulphuric acid. *Leather* (p. 259) in raw condition is practically valueless as a source of nitrogen on account of the extreme slowness with which it decomposes. Even when roasted or steamed and ground very fine, it has little value. However, if leather is ground very fine and then carefully treated with strong sulphuric acid, it acquires a degree of availability about equal to that of ground fish. The nitrogen in *hair* and *wool-waste* is of much the same character of availability as that in raw leather. *Farm manure*, as already shown (pp. 300-340), varies in availability according to a variety of conditions. The nitrogen in urine becomes quickly available, almost as readily as ammonia; under favorable conditions, it requires only a few hours to change the nitrogen of urine into ammonium carbonate. The nitrogen in the solid portion of animal manure is not quickly available, not as quickly available as the nitrogen in the food before consumption, because in the process of animal digestion the less-resistant portions of nitrogen compounds are retained in the body, while the more-resistant portions remain undigested and pass from the body as solid excrement. The nitrogen in *green crops* varies with different conditions, but is, in general, more quickly available than that in the solid portion of animal manure; the decomposition may be hastened by treatment, previous to plowing under, with good quality of mixed farm manure or with liquid manure, which furnishes the micro-organisms that produce decomposition. *Muck, peat* and similar materials usually contain very little nitrogen that becomes readily available (p. 123). When such materials are used on soils as a source of nitrogen, they should be applied in rather large amounts, and the decomposition may be hastened by treatment with freshly slaked lime at the rate of 1,000 to 1,500 pounds an acre.

Availability tests of nitrogen-containing materials.— Numerous experiments have been made to determine the

comparative plant-food value of nitrogen in the more common animal and vegetable materials, both by comparative tests in growing crops and by chemical methods. While the results of vegetation experiments have not been uniform,



AVAILABILITY OF LEATHER IN DIFFERENT FORMS SHOWN BY PLANT GROWTH. CONNECTICUT (NEW HAVEN) STATION.

they serve as a fair guide in regard to the plant-food availability. Taking results secured with nitrate nitrogen as 100, the following table can be made:

TABLE 40—COMPARATIVE PLANT-FOOD VALUE OF NITROGEN IN ANIMAL AND VEGETABLE MATERIALS

Material containing nitrogen	Availability or crop-producing value
Sodium Nitrate	100
Ammonium sulphate	95
Dried blood	70
Cottonseed-meal	70
Castor-pomace	70
Fish, dried and ground	65
Horn and hoof meal	65
Leather, dissolved with acid	65
Leather, steamed	15
Leather, roasted	10
Leather, raw	2

It must be understood that these figures are only approximate. They indicate what is fairly true when the materials are used on the same crop under the same set of conditions.

tried is treatment of the water-insoluble portion of organic matter with potassium permanganate and an alkali. For example, a mixture of dried blood and cottonseed-meal is found by this method to contain about 72 per cent. of available nitrogen, while a mixture of treated leather, garbage tankage, and peat contains only 44 per cent. The method is useful, at least, in enabling chemists to distinguish readily available from unavailable nitrogen, even if it cannot show exactly how much nitrogen a crop can use during a growing season.

Availability of different forms of phosphorus or phosphate compounds.—The composition and general properties of these compounds have been previously treated (pp. 261-277); we will discuss here only those points that relate particularly to the availability of the different phosphorus compounds that form the chief source of plant-food supply.

(1) *Calcium acid phosphate,* soluble calcium phosphate or mono-calcium phosphate (pp. 45-49), is the one phosphorus compound, which, so far as we now know, is directly absorbed by plant-roots; it is, at least, the only source of quickly available phosphorus for agricultural purposes. This compound dissolves under ordinary conditions at the rate of about 1 part in 100 parts of water. This is the chief phosphorus compound of superphosphates or acid phosphates and of double superphosphate.

(2) *Di-calcium phosphate* or "reverted" phosphate (pp. 45-49)—When applied to soils, soluble calcium phosphate generally undergoes a change in composition, forming with the calcium carbonate of the soil di-calcium phosphate (p. 48), known also as "reverted" and "citrate-soluble" phosphate. This compound is less soluble in water than the

acid phosphate, but is fairly soluble in water containing carbon dioxide, as in the case of soil water. While one part of reverted phosphate requires 7,500 parts of pure water to dissolve it, it requires only 1,800 parts of carbonated water. In the case of soils containing large amounts of iron or aluminum compounds and only small amounts of calcium carbonate, the reverted phosphate is an iron or aluminum compound, which is very slow to dissolve in water and, therefore, practically unavailable as plant-food for prompt use. This condition means loss of applied soluble phosphate, at least, in large part, so far as the season's crop is concerned; it can be prevented by keeping the soil well supplied with calcium carbonate (pp. 363-393).

The question naturally arises as to why it is not better to apply phosphorus directly in the form of "reverted" phosphate instead of applying it as soluble phosphate, which soon changes to the reverted form. Even though phosphate applied in soluble form becomes reverted in soils before it can be used by a crop, it is better to apply it in the soluble rather than the reverted form. When the soluble phosphate is applied to the soil, it goes into solution as quickly as the amount of water in the soil permits and is at once distributed uniformly and widely among the soil particles; when it reverts and goes into the precipitated form, the soil particles are coated with this very finely divided phosphate and under these circumstances it is in the best possible condition for undergoing solution in the soil water and coming into contact with plant roots. On the other hand, if the phosphate is applied to the soil in the reverted form, even if very finely divided, it is impossible to get it as thoroughly and uniformly distributed as in the case of a solution.

(3) *Tri-calcium phosphate* or insoluble phosphate (pp. 45 and 49) is less easily soluble in water than the preceding forms. One part requires about 50,000 parts of pure water for solution under ordinary conditions, but the solubility in water is considerably increased by the presence

of carbon dioxide and also of some materials that are applied to soils as fertilizers, among which are sodium nitrate, ammonium sulphate and potassium sulphate; gypsum and iron compounds make it less soluble. The presence of decaying organic matter in soils, furnishing carbon dioxide and free acids, creates conditions which make the insoluble phosphate dissolve more quickly, and so more readily available as plant-food. Tri-calcium phosphate has been quite generally regarded as of little value as a source of phosphorus for plants, but recently it has come to be increasingly valued under certain conditions, especially where soils are well supplied with decaying organic matter and calcium carbonate. The presence of calcium carbonate is of special value in preventing the formation of the very insoluble iron or aluminum phosphate. One form in which insoluble phosphate is most extensively used is that of finely ground phosphate rock, commonly known as "floats" (p. 264). The availability of such insoluble phosphates depends, other things being equal, upon the fineness of its particles; extreme fineness is essential to promote more uniform distribution in soil and to offer more extensive surface for attack of dissolving agents. On muck soils that are definitely acid, insoluble phosphate in the form of "floats" has often been found to give as good crop yields as the dissolved phosphate. The availability of insoluble phosphate appears to vary for different crops. For example, turnips appear often to use fine-ground insoluble rock-phosphate with as beneficial results as acid phosphate. Barley and corn appear generally to do better with acid phosphate. Ground rock-phosphate on acid soils gives better results than iron or aluminum phosphate. These results, however, often depend upon various soil conditions as much as upon the kind of crop.

(4) *Bone.*—The availability of the tri-calcium phosphate in animal bone is greater than in ordinary tri-calcium phosphate from mineral sources when the condition of fineness is the same. This is due to the fact that the phosphate in bone is intimately associated with organic nitrogenous mate-

rial that decomposes easily under ravorable soil conditions and the insoluble phosphate is made gradually soluble during this process of decomposition. The phosphate in raw bone becomes available less easily than in bone from which the fat has been removed, because the fat serves to retard the decomposition of the bone and also to make impossible equally fine grinding. Increased fineness of bone increases the availability. Under favorable conditions, it is believed that from one-third to one-half of the phosphate in bone becomes available for crops during the first growing season after its application. The balance becomes available approximately in the course of two or three years. So much depends upon soil conditions that great variation inevitably occurs.

(5) *Basic-slag phosphate* is believed, on the basis of experimental evidence, to be about one-half as quickly available as soluble calcium phosphate, but, of necessity, much depends on special soil conditions and crops. This material has shown good results on acid soils and especially on swampy and wet soils. Its degree of availability is dependent also upon its fineness of division.

Availability of potassium compounds.—All the potassium salts commonly used in agriculture, the sulphate, chloride, nitrate and carbonate, are easily soluble in water (p. 51). They are, therefore, in condition to be distributed promptly and uniformly when the soil contains sufficient moisture. In this dissolved condition they are ready for direct use by plant-roots. However, after potassium salts are applied to a soil and go into solution, considerable time may elapse before the solution has a chance to be used by a crop. Meanwhile, the soluble potassium compounds are undergoing reactions or exchanges with some of the soil constituents, by which the potassium changes into compounds that are less easily soluble (p. 184). This fixation prevents excessive loss of potassium by leaching. In the soil water the potassium again slowly changes back to soluble compounds as rapidly as called for by crop demands.

EFFECT OF FERTILIZING MATERIALS UPON SOILS

In applying plant-food materials to soils, the purpose is to furnish nutriment for crops, and the thought of farmers has naturally not gone farther than this one point. But we are coming to understand that the application of a chemical compound to the soil may, and usually does, do much more than furnish plant-food. What we may call secondary effects take place and these often influence the chemical, physical and biological properties of the soil, and, therefore, may affect crops in ways not anticipated. The secondary effects thus produced by fertilizers deserve our consideration, because they have some bearing upon the selection we may make of fertilizing materials. The effects of organic materials have been previously discussed (pp. 134-136). Here we will confine our attention more particularly to definite inorganic compounds.

Effect of sodium nitrate on soils.—In applying sodium nitrate as a fertilizer, we have had in mind only the effect of nitrate nitrogen upon plants, and have simply regarded the sodium as a carrier, used on account of being the most convenient and cheapest material to be obtained; we have not usually regarded the sodium as contributing anything to the welfare or injury of the soil or crop. As a matter of fact, the sodium in sodium nitrate may be useful and it may be harmful. In what ways it may thus act we will now consider.

(1) *Beneficial effect.*—Sodium in sodium nitrate may be valuable in crop growing, not because it is in any way necessary to the direct nutrition of plants, but because of its action upon the insoluble potassium compounds in the soil, in which sodium changes places with potassium and a soluble potassium compound results. To such an extent may this action take place in many soils, especially clays, that an application of sodium nitrate brings so much potassium into

solution as to make unnecessary the application of potassium compounds.

(2) *Injurious effect.*—When sodium nitrate is used alone continuously on a soil for a long time, it may injure seriously the soil, destroying its granular or crumb structure (p. 101). Under such conditions the soil remains wet and puddles badly (p. 96), if disturbed before it dries. Such land becomes intolerably sticky after rains and dries into hard, unmanageable lumps, so much so that it is often difficult to secure a start for young plant roots except in very favorable seasons. These effects are caused, it is now believed, by the sodium contained in the nitrate and left behind after the nitrate is taken into the plant. It may be explained that a plant does not take the whole compound of sodium nitrate into its roots (p. 170), but takes the nitrate and leaves practically all of the sodium behind in the soil. This residue of sodium combines readily with the carbon dioxide in the soil water and becomes sodium carbonate. It is well known that alkali carbonates, such as sodium carbonate, produce deflocculation (p. 104), that is, cause the soil grains or crumbs, which are necessary to a good soil structure, to fall apart into the very fine particles composing the larger crumbs. It has been observed in such cases that the finest material of the soil is slowly removed in the course of years. Bad soil structure, thus produced, is very difficult to correct. The use of calcium compounds, such as hydrate or carbonate, under these conditions only makes matters worse. The most effective remedy is the application of acid phosphate, ammonium sulphate or gypsum, furnishing acid to neutralize the alkali of the sodium carbonate and convert it into a harmless compound.

(3) *Effect on soil acidity.*—In the preceding paragraph we have noted the production of sodium carbonate in the soil from the use of sodium nitrate. This sodium carbonate neutralizes acids and prevents a soil becoming acid. It therefore saves the calcium carbonate of the soil. Generally

speaking, the effect of 100 pounds of sodium nitrate in the soil, when used by plants, saves about 100 pounds of calcium carbonate.

Effect of use of ammonium sulphate on soils.—Ammonium sulphate produces in soils a chemical condition the reverse of that produced by sodium nitrate. The ammonia is changed in the soil into nitric acid (p. 204), leaving free or uncombined sulphuric acid, which combines with calcium carbonate present in the soil. The result is that with long-continued use of ammonium sulphate as a fertilizer, we gradually use up the calcium carbonate of the soil and then have what we call an acid soil (p. 140). Under such circumstances, additional application of ammonium sulphate or of organic nitrogen does no good, because the nitrogen is not changed into nitrate nitrogen by bacteria in the presence of acids (p. 209). Therefore, crops cannot thrive. In such cases the simplest remedy is to apply calcium (lime) compounds, either the carbonate or slaked lime (p. 379). This condition can be prevented by the application of calcium carbonate or by using along with ammonium sulphate some sodium or calcium nitrate. It is obvious that it is well never to use either sodium nitrate or ammonium sulphate exclusively for long periods of time, but to alternate them, or, better, always use them together, unless other materials are applied to prevent the injurious action of either when used alone.

Effect of use of calcium nitrate on soils.—Calcium nitrate (lime nitrate) leaves in the soil, after the nitrate has been absorbed by plant-roots, calcium, which becomes carbonate under normal conditions, and is on this account a more desirable compound to use than sodium nitrate, which leaves sodium carbonate,

Effect of use of ammonium nitrate and potassium nitrate on soils.—When ammonium nitrate is applied to soils, the nitrate is used as such and the ammonia is converted into nitrate and then absorbed. Under conditions which enable plants to use all the nitrogen of this compound,

no residue is left in the soil, so that, theoretically at least, the soil is left in the same condition as before so far as the effect of the ammonium nitrate is concerned. The ammonium nitrate itself undoubtedly has some direct chemical and physical effects upon some of the soil constituents before it is used by plants, but we are here considering more particularly the effects of compounds left as residues after the plant has absorbed the plant-food constituents.

In the case of potassium nitrate both constituents may be conceived as being used by the growing plant and, under ordinary conditions, leaving no residue.

Effect of use of calcium cyanamid on soils.—The nitrogen of the cyanamid is changed to ammonia and then to nitrate, forming probably calcium nitrate, which after being used by the plant leaves calcium to form the carbonate. It has been stated that under some conditions calcium cyanamid forms in the soil a compound called dicyandiamid, which has a poisonous effect upon plants, though probably no particular effect upon the soil itself.

Effect of use of superphosphates on soils.—Whether we use a superphosphate (p. 271) made by dissolving rock-phosphate or bone, we have in all acid phosphates, dissolved bone, etc., a mixture of acid calcium phosphate and hydrated calcium sulphate (gypsum). We have previously seen (p. 182) that the soluble phosphate is more or less quickly changed in the soil into di-calcium or "reverted" phosphate through combination with calcium or calcium-carbonate. When this compound again becomes soluble phosphate, it is probably absorbed as a whole without leaving any residue, or if any is left, it is calcium, which becomes carbonate under normal soil conditions. The effects on the soil of gypsum contained in superphosphates are more pronounced than those of the acid calcium phosphate. Theoretically at least, calcium sulphate applied to soils may have several different effects. The most common one attributed to it is conversion of certain insoluble potassium compounds into soluble potassium sulphate, the calcium taking the place of potassium in

the insoluble compound. The potassium sulphate thus formed is utilized as plant-food; the plant uses larger amounts of potassium than of sulphate, so that much of the sulphate is left in the soil as free sulphuric acid. If calcium carbonate or some other basic compound is not present in sufficient amounts to neutralize the acid, there may be an accumulation of sulphuric acid or of its reaction products, with continuous applications of superphosphate, and the soil in time becomes acid. Superphosphates have gained the reputation of producing "sour" soils, and the popular explanation has been that it was due to the soluble phosphate, which is known to be an acid salt, while in reality it is due rather to the calcium sulphate, present in superphosphates.

Effect of use of potassium compounds on soils.—It would naturally be thought that when we apply to soils potassium chloride or sulphate, the plant after absorbing the potassium and rejecting most of the hydrochloric or sulphuric acid would tend to bring about an acid condition in the soil as the result of continued application of such potassium compounds. We have previously stated (p. 184) that when these potassium salts are applied to soils they are usually converted into insoluble compounds, their acids combining with calcium or magnesium to form the chloride or sulphate of these elements. These compounds, the chloride and sulphate of calcium and magnesium, are found extensively in drainage waters. In this way, the acid constituents of applied potassium chloride and sulphate are removed from soils to such an extent as to prevent accumulation and acidity. Of course the presence of an abundance of calcium carbonate in soils favors the rapid formation and removal of any excess of hydrochloric or sulphuric acid.

Effect of use of potassium carbonate on soils.—Potassium carbonate, the chief potassium compound in wood-ashes (p. 283), when applied to soils is, on account of its easy solubility and alkalinity, a quick and powerful neutralizer of acids. If used in excess, the effect is the same

as in case of sodium carbonate (p. 438), to destroy the crumb structure of the soil.

ADAPTATION OF FORMS OF PLANT-FOODS TO CROPS

Each crop possesses individual characteristics, varying from others in many ways; among these differences we may mention for our purpose the habits of root growth, so-called "feeding-power" (p. 172), season of growth, etc. On account of such variations, some forms of plant-food constituents are better adapted to promote normal growth than others. Another difference has been found in some cases in that the character and commercial quality of the crop are affected favorably by one plant-food compound and unfavorably by another compound containing the same plant-food constituent. In furnishing fertilizers it is desirable, as a matter of their most effective use, to take into consideration these individual peculiarities so far as we have learned them. We will now consider some of the applications of the more important facts bearing on these relations.

Adaptation of fertilizers to feeding-habits of crops, season of growth, etc.—In discussing those individual characteristics of plants that interest us here, we can conveniently divide agricultural plants into several different classes; the members of each class, while differing in many ways, have in common certain resemblances that are of importance in this connection. The different classes of farm crops, as we shall consider them here, are: (1) Cereal, (2) leguminous, (3) grass, (4) orchard, (5) root, and (6) garden crops.

(1) *Cereal crops.*—These crops are comparatively shallow-rooted; starting near the surface, the main roots send out feeding roots in every direction, occupying the upper layer of soil extensively before the end of the growing season and also reaching more deeply down into the soil. On account of location of the root system, fertilizers are most effectively applied in the upper layer of soil; in the case

of very soluble forms of compounds, the nearer they are placed to the surface the better, provided rain can be relied upon to dissolve them. Such cereals as barley, oats, rye and wheat need a large proportion of their nitrogen during the early part of the growing season and at this time there is apt to be a lack of nitrate nitrogen because nitrification does not get well started until the weather has warmed the soil (p. 204). On this account, the application of nitrate in spring to these crops is usually found most beneficial. In the case of corn, which has a long growing season, making its best growth after the other cereals have matured, nitrogen is better applied for the most part in the form of organic materials, since nitrification is most active by the time the corn crop makes its largest demands. For this reason farm manure gives good results. All cereals are generally benefited by application of soluble calcium phosphate. Oats and corn appear to be able to utilize some forms of plant-food in soils to better advantage than wheat does. Barley should have comparatively small applications of soluble nitrogen compounds, since the quality of the grain for malting purposes is injured by too much nitrogen in the early stages of growth. Owing to the comparative shallowness of the root system of barley, it cannot forage for phosphorus as well as other cereals and therefore should be furnished with a supply.

(2) *Leguminous crops* have, for the most part, comparatively long roots, which in some cases go deep down into the soil; they are able to absorb plant-food compounds from the soil with much vigor. Their chief distinguishing characteristic is their power to make use of atmospheric nitrogen (p. 215), which reduces greatly the amount of nitrogen that needs to be furnished. In starting some of the leguminous crops on poor soils, alfalfa particularly, application of sodium nitrate is helpful. On most soils, the fertilizing materials that are found most effective on leguminous crops are calcium, potassium and phosphorus compounds.

(3) *Grass crops* are generally shallow-rooted and obtain their food supplies from a comparatively narrow range of

soil. Grasses in permanent meadows and pastures are greatly benefited by fertilizers. Nitrogen in soluble forms is especially useful because the chief part of the crop consists of stems and leaves, the growth of which is largely dependent on nitrogen (p. 65). In grass lands where the crop has occupied the soil for over a year, decomposition changes are less active because the air supply is reduced; nitrification is, therefore, very slow and the crop is generally in condition to respond promptly to nitrogen feeding.

(4) *Orchard crops* are capable of collecting food from a wide extent of soil and at considerable depth. They should have a continuous supply of plant-food materials in moderate amounts and in fairly soluble form, but they should not be so fertilized as to make rapid growth of new wood, or to prolong their growth too late in the fall.

(5) *Root crops* do not have the ability to range through wide reaches of soil; each plant must take its food from a comparatively limited area. It is important, therefore, to supplement the soil food supply with fertilizers in fairly soluble forms. Turnips appear to respond to phosphate compounds, while carrots, beets, parsnips, etc., are benefited by available forms of nitrogen.

(6) *Garden crops* include plants differing greatly in their habits and seasons of growth. The chief purpose for which these crops are grown is the production of leaves and stalks, in most cases, of a tender, succulent character. The desired quality is dependent on rapidity of growth, and, therefore, abundance of soluble nitrogen is essential. Enough available phosphorus and potassium must be insured to enable the nitrogen to accomplish its work most effectively. Farm manure in large amount is often used.

Adaptation of fertilizers to quality of product.—We have already in the preceding paragraphs illustrated the fact that some crops thrive better on sodium nitrate at certain stages of growth than at others. But there are some cases in which the quality of the product is affected favorably by some

constituent of plant-food in the form of one compound and unfavorably by another compound containing the same constituent. This is strikingly shown in the case of tobacco. The quality of tobacco is injured by chlorine. Potassium carbonate or sulphate is, therefore, used and not chloride, in tobacco fertilizers. It has been stated that the quality of sugar-beets is better with potassium sulphate than with chloride. This probably refers to the character of crystallization, which causes less sugar to remain in molasses. Much has been said about the effect of potassium salts upon potatoes. So far as facts are available at the present time, it is believed that on light soils, either chloride or sulphate of potassium can be used with equally satisfactory results; but, on clay soils and especially in wet seasons, the use of chloride appears to produce potatoes which contain less starch and which are heavy or watery when cooked, while the use of sulphate produces potatoes containing more starch and of mealy texture when cooked. Probably many new facts in this line remain to be discovered, which will enable us to control more or less directly the quality of crops.

COMPARATIVE COST OF PLANT-FOOD MATERIALS

The materials used in supplying plant-foods to crops vary in cost for the same plant-food constituent. Considerable saving in the purchase of fertilizing materials can be made by a careful selection based upon a study of market values. In many cases the less expensive form will answer the farmer's purpose as well as the more expensive. Other things being equal, it is economy to purchase the cheapest form that will meet our needs. Prices are constantly varying and we can discuss the subject only in an illustrative way. Later (p. 482) we will give more specific information regarding the purchase of fertilizing materials.

Nitrogen-containing materials.—We cannot do better in discussing prices of nitrogen than to illustrate by making

use of quotations prevailing at the time of this writing. In the following tabulated statement are given (1) the retail price per ton in bags f. o. b. New York City for nitrogen in three different forms, (2) the percentage of nitrogen, (3) the number of pounds of nitrogen in one ton, and (4) the cost of one pound of nitrogen.

TABLE 41—RETAIL COST OF NITROGEN IN DIFFERENT MATERIALS

Material	Retail price per ton	Per cent of nitrogen	Pounds of nitrogen in one ton	Cost of one pound of nitrogen
Sodium nitrate	$46.00	15.65	313	14.7 cents
Ammonium sulphate	66.00	20.60	412	14.6 "
Dried blood	60.00	13.20	264	22.7 "
Calcium cyanamid ..	53.00	18.00	360	14.7 "

An examination of the figures in the last column shows that one pound of nitrogen in the form of sodium nitrate or of ammonium sulphate or of cyanamid, costs a little less than 15 cents a pound, but in dried blood the cost is nearly 23 cents, 8 cents more a pound. At these prices dried blood is hardly to be regarded as within reach, when ammonia and nitrate nitrogen can be purchased for so much less. Nitrogen in such materials as wool-waste, ground leather, hair, muck, etc., can be purchased for much less, but these forms of nitrogen are not usually economical at any price.

Phosphorus-containing materials.—Soluble calcium phosphate can be purchased most cheaply in the form of acid phosphate. Genuine dissolved bone and bone-black are found only in small amounts and their phosphorus comes relatively high in price. The market materials containing only the plant-food element of phosphorus without nitrogen or potassium are acid phosphate, basic-slag phosphate and ground phosphate-rock or "floats." These exist in different forms of availability, but we will give them in the following table with their retail prices:

TABLE 42—COST OF PHOSPHORIC ACID (PHOSPHORUS) IN DIFFERENT MATERIALS

Material	Retail price per ton	Per cent. of phosphoric acid	Pounds of phosphoric acid in one ton	Cost of one pound of phosphoric acid
				Cents
Acid phosphate ...	$13.00	14 (6.2P) available	280 (124P)	4.6 (10.5P)
Basic-slag phosphate	14.25	16 (7. P) mostly available	320 (140P)	4.5 (10.2P)
Ground rock phosphate.........	8.00	28 (12.3P) insoluble	560 (243P)	1.4 (3.2P)

P, phosphorus.

These prices are, of course, not comparable because the availability of the phosphorus is not the same. For most purposes where quick action is desired, as for example, in starting a young crop, soluble phosphate is necessary. For moderate availability, basic slag can be used. When one can make use of ground rock-phosphate (p. 263), this is by far the cheapest form of phosphorus, but it is ordinarily useless for immediate results.

Materials containing nitrogen and phosphorus.—The comparison of prices in case of materials containing more than one plant-food constituent is somewhat more complicated, but the results are readily comparable in materials like bone, tankage, fish, etc., as shown in the following table:

It is obvious that fish-scrap, like dried blood, is selling for more than it is worth to farmers. The nitrogen in bone

TABLE 43—COST OF NITROGEN AND PHOSPHORUS IN BONE, TANKAGE, ETC.

Material	Retail price per ton	Per cent of nitrogen	Per cent of phosphoric acid	Pounds of nitrogen	Pounds of phosphoric acid	Cost of one pound of nitrogen	Cost of one pound of phosphoric acid
						cents	cents
Ground steamed bone........	$26.00	1.0	24.0	20	480	18.0	3.6
Raw bone	30.00	3.3	20.0	66	400	19.4	3.9
Bone-tankage ...	24.00	4.0	18.0	80	360	15.8	3.2
Bone-tankage ...	28.00	6.5	9.0	130	180	16.8	3.4
Fish scrap ground......	55.00	8.0	5.0	160	100	30.6	6.1

is moderately high as compared with nitrate and other inorganic forms, but is lower than nitrogen in blood. The cheapest forms of organic nitrogen are found in nitrogenous tankage. Phosphorus is cheapest in tankage; it is higher in raw than in steamed bone, although it is more available in the steamed bone on account of increased fineness and absence of fat.

Potassium-containing compounds.—Of all commercial plant-food materials, the potassium compounds have varied least in price, owing to the German monopoly of the supply. The following tabulated statement gives a fair idea of the relative prices of the different materials:

TABLE 44—COST OF POTASSIUM IN DIFFERENT MATERIALS

Material	Retail price per ton	Per cent. of potash (K_2O)	Pounds of potash (K_2O) in one ton	Cost of one pound of potash (K_2O)
				cents
Potassium chloride (muriate)	$41.00	50 (41.5K)	1000 (830K)	4.1 (5.0*)
Potassium sulphate	48.00	48 (40.0K)	960 (800K)	5.0 (6.0*)
Potassium carbonate..........	79.00	60 (50.0K)	1200 (1000K)	6.5 (7.9*)
Kainite	12.00	12 (10.0K)	240 (200K)	5.0 (6.0*)
Wood ashes	12.00	5 (4.0K)	100 (80K)	12.0 (15.0*)

K, potassium. *Figures in parentheses give cost of 1 pound of potassium (K).

The cost of wood-ashes makes their use a luxury as a source of potassium, and the cost is still high even if we make generous allowance for the calcium and phosphorus compounds. For most crops, chloride answers every purpose and costs least. Commercial potassium carbonate is little used at present; this can be used by those who want a substitute for the potassium carbonate in wood-ashes.

Whether we consider unmixed fertilizing materials or mixed commercial fertilizers, the constant aim should be to obtain, in purchasing, the largest amounts of nitrogen, phosphorus and potassium in available form that we can buy for one dollar, instead of as many pounds as possible of material without reference to the amount and character of plant-food contained in it.

CHAPTER XXIV

FACTS ABOUT COMMERCIAL FERTILIZERS

Commercial fertilizers are manufactured preparations, made by mixing plant-food materials of different kinds, and commonly sold under special trade-names. They are also known as *artificial, prepared* or *manufactured* fertilizers or manures. When they consist only of inorganic materials, they are often called *chemical* fertilizers or manures. The term "agricultural chemicals" is often applied to such materials as sodium nitrate, ammonium sulphate, calcium cyanamid, calcium nitrate, potassium chloride, potassium sulphate, superphosphates, etc.

The materials used in making commercial fertilizers include manufactured products, substances found in, or prepared from, natural deposits, and, in addition, materials that form by-products of numerous industries, obtainable only through the channels of trade. These materials are described in Part II. (pp. 244-287), and include familiar substances.

While commercial fertilizers contain numerous constituent elements, their chief value depends on the presence of only three forms of plant-food, and these are compounds of *nitrogen, phosphorus* and *potassium*. Their agricultural value varies in accordance with the forms and amounts of these different plant-food compounds. It may be added that in all fertilizers containing phosphorus this element is in combination with calcium, and in superphosphates there is also present hydrated calcium sulphate (gypsum).

Commercial fertilizers are known as *complete* and *incomplete*. Complete fertilizers, also called general fertilizers, are those containing the three plant-food constitu-

ents, nitrogen, phosphorus and potassium. Incomplete fertilizers, known sometimes as special fertilizers, are those containing only one or two of the three important plant-food constituents.

The value of the commercial fertilizers used in the United States is estimated to be not less than $100,000,000 a year and it is probably more than this sum. It is, therefore, a subject of importance which deserves thorough discussion in all of its relations to consumers. We shall consider the subject under the following headings:

1. Meaning of guarantee-analysis.
2. High-grade and low-grade fertilizers.
3. Brand names of fertilizers.
4. Meaning and use of commercial valuations of fertilizers.
5. Fertilizer laws: objects, methods..
6. Advantages and disadvantages of commercial fertilizers.

MEANING OF GUARANTEE-ANALYSIS

In all states where fertilizers are used, manufacturers are required by law to state on each package what percentage of nitrogen, phosphorus (phosphoric acid, P_2O_5), and potassium (potash, K_2O), the fertilizer contains; in some states they are also required to state the source or form of the nitrogen and of the potassium.

In examining the guarantee-statements of analysis of different manufacturers, we find much variation in the terms used. Some forms are simple, stating only essential facts of composition, while others are needlessly complicated and confusing to farmers. We will now consider the different terms found in such guarantees. We will first give illustrations of a complicated and faulty form of guarantee-analysis, and then of a simplified form.

Faulty Form of Guarantee-Analysis

Nitrogen	2.0	to	2.5	per cent.
Equal to ammonia	2.4	"	3.0	"
Soluble phosphoric acid	6.0	"	8.0	"
Equal to bone phosphate of lime	13.0	"	17.5	"
Available phosphoric acid	8.0	"	10.0	"
Equal to bone phosphate of lime	17.5	"	22.0	"
Insoluble phosphoric acid	1.0	"	2.0	"
Equal to insoluble bone phosphate	2.3	"	4.5	"
Total phosphoric acid	10.0	"	12.0	"
Equal to total bone phosphate of lime	22.0	"	26.0	"
Potash	6.0	"	8.0	"
Equal to sulphate of potash	11.5	"	14.8	"

Simple and Sensible Form of Guarantee-Analysis

Nitrogen	2	per cent.
Available phosphoric acid	8	"
Potash	6	"

The simple form conveys all the information afforded by the first without confusing or misleading. We would call attention here to the fact that in the first form, two percentages are given in each case, as nitrogen, 2 to 2.5, while in the second only one figure is given, 2 per cent. The old custom of stating each guarantee in two different percentages was supposed to be based on the difficulty of making an exact mixture; as a matter of fact, the usage often had its foundation in an attempt to make farmers think that there were larger amounts of fertilizing compounds present than there were actually. When such double guarantees are used, manufacturers are legally held only to the lower figure; the higher figure is, therefore, a meaningless ornamentation and is apt to be misleading, so far as the farmer is concerned. The more progressive manufacturers of fertilizers have discontinued this faulty practice.

We will now take up the different terms that are liable to appear in guaranteed statements of analysis, and will explain their meaning.

Terms used in stating guarantee of nitrogen.—We find one or more of the following terms commonly used in stating the guaranteed percentage of nitrogen in com-

mercial fertilizers: (1) Nitrogen, (2) ammonia, (3) nitrogen equal (or equivalent) to ammonia, (4) nitrogen from animal matter, (5) nitrogen from organic matter, (6) total available nitrogen.

(1) *Nitrogen,* as used in statements of guaranteed analysis, refers to the total amount of nitrogen present in the fertilizer without reference to the form of combination in which it exists. It does not state whether the nitrogen is present as nitrate, ammonia, or organic nitrogen, but simply that, whatever form it is in, there is the specified amount.

(2) *Ammonia* was formerly used exclusively in stating the amount of nitrogen in fertilizers and is still used extensively in commercial market quotations, and among dealers in fertilizers, regardless of whether the material in question contains any ammonia compound. The use of the term ammonia in a guarantee-analysis is misleading to most farmers, because they suppose that nitrogen and ammonia, are the same. A pound of ammonia contains less than a pound of nitrogen because ammonia consists of nitrogen in combination with hydrogen (p. 39); 100 pounds of ammonia contain 82 1-3 pounds of nitrogen and 17 2-3 pounds of hydrogen, or, stated another way, 100 pounds of nitrogen will make 121½ pounds of ammonia. The figure giving the percentage of nitrogen as ammonia is, therefore, higher than that for nitrogen. In purchasing fertilizers, farmers should insist on a guaranteed statement of the percentage of nitrogen and should pay no attention whatever to the ammonia percentage. As a matter of fact, commercial fertilizers usually contain no actual ammonia compound whatever and to state the nitrogen as ammonia under such circumstances is misleading, to say the least.

(3) *Nitrogen equal or equivalent to ammonia* is a form of expression which means simply that, if the nitrogen

were present as ammonia, there would be the percentage stated; it does not usually mean that any form of ammonia is present.

(4) *Nitrogen from animal matter* is occasionally found in guarantees and means that the fertilizer contains such materials as dried blood, ground meat, fish, bone, horn or hoof meal, etc., but does not necessarily exclude useless leather and hair.

(5) *Nitrogen from organic matter* furnishes very little information, except that nitrate, ammonia or cyanamid nitrogen is not present; this form of statement does not exclude unavailable forms of organic nitrogen, such as leather, hair, muck, etc.

(6) *Total available nitrogen* implies that all the nitrogen in the fertilizer is available as plant-food, but gives no information as to whether it is quickly or slowly so.

Terms used in stating guarantee of phosphorus as phosphoric acid.—While all the needed information in regard to the amount of phosphorus in a fertilizer can be stated in two or three forms, we often find twice as many. Among the different forms of statement are the following: (1) Phosphoric acid, (2) soluble phosphoric acid, (3) citrate-soluble phosphoric acid, (4) "reverted" phosphoric acid, (5) "precipitated" phosphoric acid, (6) available phosphoric acid, (7) soluble and available phosphoric acid, (8) insoluble phosphoric acid, (9) total phosphoric acid, (10) phosphoric acid equal (or equivalent) to bone phosphate of lime.

Before discussing the meaning of the foregoing terms, we will briefly review some facts regarding phosphoric acid compounds in fertilizers. Phosphorus in the form of phosphoric acid or phosphate compounds is usually present in fertilizers in the form of three different compounds, (a) acid calcium or mono-calcium phosphate (p. 47), which is soluble in water, (b) di-calcium or

"reverted" phosphate (p. 47), which is insoluble in water but soluble in a dilute solution of ammonium citrate, and (c) tri-calcium or insoluble phosphate (p. 47), which is not soluble either in water or in a solution of ammonium citrate. The *total* phosphoric acid includes all the phosphorus in the fertilizer whether present in one or two or, as is usually the case, in all three of these forms. *Available* phosphoric acid includes the *sum of the water-soluble and "reverted" or citrate-soluble,* and is equal to the *total* phosphoric acid less the *insoluble.* Therefore, all the needed information can be furnished by stating simply the amount of phosphoric acid in these three forms—soluble, "reverted" and insoluble, and can usually be further simplified by specifying only available. We will now discuss some of the other special terms.

(1) *Phosphoric acid,* as used for the purpose of stating the amount of phosphorus in the form of phosphate compounds, is a compound consisting of phosphorus and oxygen (P_2O_5), which is never found by itself in fertilizers but only in combination with calcium (lime). As already explained (p. 43), it is simply an arbitrary term long used by chemists in stating the percentage of phosphorus. Following the usage of substituting nitrogen for ammonia, it would be really simpler and more consistent to state the amount as actual phosphorus than, as we now do, phosphorus in combination with a certain amount of oxygen.

(2) *Soluble phosphoric acid* means the phosphorus existing as acid calcium phosphate ($CaH_4(PO_4)_2$ p. 45), which, as already stated, is soluble in water.

(3) *Citrate-soluble, "reverted"* and *"precipitated,"* are terms used to indicate phosphorus when present as dicalcium phosphate ($Ca_2H_2(PO_4)_2$, p. 45).

(4) *Available phosphoric acid,* or *soluble and available,* includes the sum of water-soluble and citrate-soluble (the mono- and di-calcium phosphates).

(5) *Insoluble phosphoric acid* applies to that present as tri-calcium phosphate ($Ca_3(PO_4)_2$, p. 45).

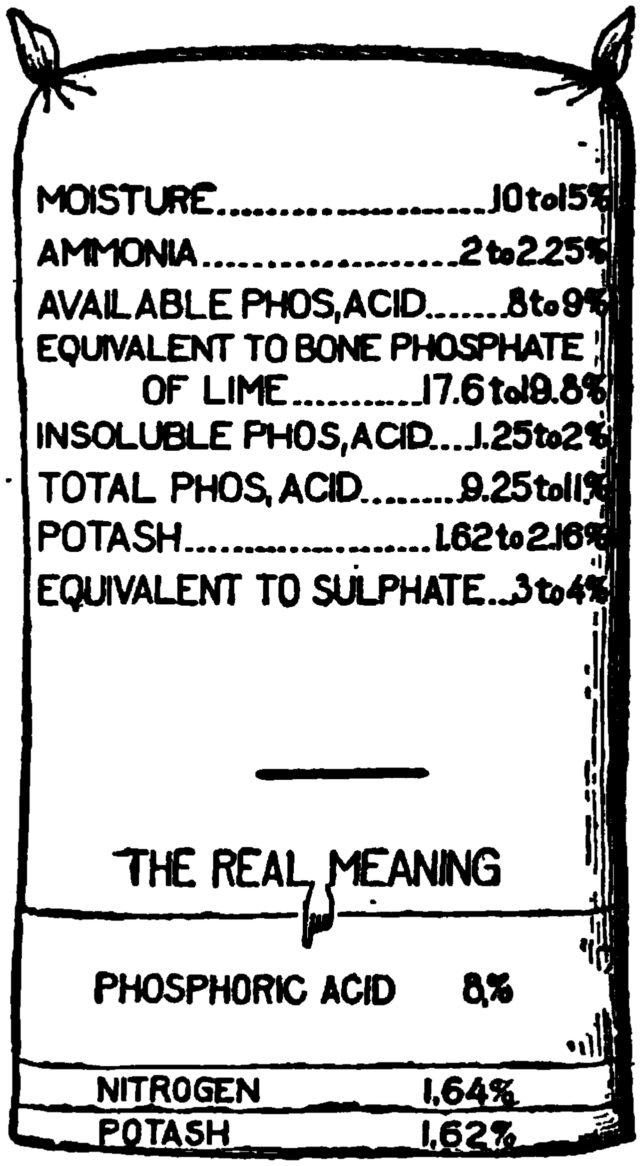
(6) *Total phosphoric acid* means the sum of the soluble, reverted and insoluble, or all phosphorus present whatever the form.

(7) *Phosphoric acid, equal to bone phosphate of lime,* is an expression which usually means simply nothing more than insoluble. The expression is misleading, since it is often taken by farmers to mean that the phosphorus is derived from bone. The most it means is that if the given amount of phosphorus were present as insoluble or tri-calcium phosphate, there would be the percentage of bone phosphate of lime indicated. It is misleading in another way, in that it gives a percentage more than twice as large as that given for phosphoric acid and gives the average farmer the impression that he is getting much more phosphorus than he is. The practice is objectionable on every ground from the farmer's standpoint, and should be entirely abandoned by all manufacturers, as it has been already by the more progressive.

Terms used in stating guarantee of potash.—It would be simpler, and more consistently accurate if we were to abandon the term potash and use simply potassium in place of it (p. 50), and this will probably come in time. The compound designated as potash, potassium oxide (K_2O), is never found in fertilizers and is merely an arbitrary method of expressing results of chemical analysis. Fertilizers contain potassium mainly in the form of chloride (muriate) and sulphate. The expressions used in connection with statements of guarantee-analysis of commercial fertilizers are the following: (1) Potash, potash actual, potassium oxide, (2) potash soluble or water-soluble potash, (3) potash S. or Sul. or sulphate, and sulphate of potash, (4) potash equal (or equivalent) to sulphate of potash.

(1) *Potash, actual potash* and *potassium oxide* (K_2O)

are terms which mean that if the potassium present in the form of a chloride, sulphate, etc., were in the form of potash or potassium oxide, there would be the percentage given. State laws usually require the guarantee to be stated in this form.



THE BAG AND THE PLANT-FOOD IN IT

(2) *Soluble* or *water-soluble potash* represents the amount of potassium compounds dissolving in water. The compounds most extensively used in fertilizers dissolve readily in water. The potassium compounds in tobacco are not completely soluble. Usually, manufacturers of fertilizers are required by law to guarantee the amount of water-soluble potash. If this requirement were not made, it would be possible to use ground minerals containing potassium compounds (p. 286) that are unavailable and therefore worthless as fertilizing material.

(3) *Sulphate of potash,* potash S. or Sul. are terms that mean potassium sulphate and not potassium oxide. This form of expression is not permitted by most state laws unless the amount of actual potash is given at the same time. Formerly, it was the custom to use this form of stating a potassium guarantee, because the percentage appears to be larger. This can be readily understood when we know that one pound of potassium oxide or potash contains the same amount of potassium that is found in 1.85 pounds of sulphate. For example, 10 per cent. of potash represents the same amount of potassium that 18.5 per cent. of sulphate does.

(4) *Potash equal or (equivalent) to sulphate of potash* is an expression that means or should mean simply potassium sulphate. When potassium is present as chloride, even in part, the above expression should never be used.

Suggestions to farmers regarding use of guaranteed statements of analysis.—Whenever a farmer purchases either a mixed fertilizer or separate fertilizing materials, *he should purchase only under a guarantee of specified percentage of each plant-food constituent.* Moreover, he should insist that the guarantee be in the following terms:

(1) *Nitrogen,* and this alone, should be given for all forms of nitrogen. An added statement as to whether the nitrogen is in the form of nitrate, ammonia, cyanamid, dried blood, cottonseed-meal, ground leather, etc., is necessary for full information.

(2) *Available phosphoric acid (or phosphorus),* or preferably, water-soluble and reverted separately, should be given for superphosphate materials, while for bone, untreated rock-phosphate, etc., only total phosphoric acid (or phosphorus) is really necessary.

(3) *Potash or potassium oxide (or potassium)* should always be given, though it is desirable to know, in addition,

whether the potassium is present as sulphate free from chloride or as chloride only.

(4) *When two percentages are given for each constituent, as, for example, 10 to 12 per cent. of potash, take only the lower figure into consideration, because manufacturers are held only to that and not to the higher. It would be well for farmers to purchase only fertilizers that have the one-figure guarantee.*

(5) *In examining the guaranteed analysis of a fertilizer, give attention primarily to the nitrogen, available phosphoric acid (or phosphorus) and potash (or potassium) and require the guarantee to be in these terms before purchasing.*

An ideal form of guarantee-analysis.—For full information, a guarantee-analysis should state the specific character or source of each constituent. In time such information will be required by law. As examples of what we may regard as a really informing guarantee-analysis, the following statements of analysis are given:

Desirable Forms of Guarantee Statement of Analysis

(1) Constituents are in desirable forms—

Nitrogen, total		**4 per cent**
Nitrogen in form of nitrate	2 per cent.	
" " ammonia	1 "	
" " dried blood	1 "	
Available phosphoric acid		**8 per cent**
Available phosphoric acid, soluble	5 per cent.	
" " " reverted	3 "	
Insoluble phosphoric acid	2 "	
Potash		**6 per cent**
(Potash present in form of sulphate)		

(2) In the following mixture the constituents are not the best plant-food materials in every case.

Nitrogen total		**4 per cent**
Nitrogen in form of ground leather	3 per cent.	
" " " muck	1 "	

Available phosphoric acid		**3 per cent**
Available phosphoric acid, soluble	1 per cent.	
" " " reverted	2 "	
Insoluble phosphoric acid	7 "	
Potash		**6 per cent**
(Potash present in form of chloride)		

These two analyses show the same amounts of nitrogen, total phosphoric acid and potash, but the agricultural value of the first is much greater than that of the second and this difference of value would not be shown in the case of nitrogen if only total nitrogen were stated and not the forms in which it is present.

How to find equivalent values of a plant-food constituent in different compounds.—When a guarantee-statement of analysis is given only in the form of ammonia, it will always be desirable to know just how much nitrogen that amount of ammonia is equal to; similarly, when only bone phosphate of lime ($Ca_3(PO_4)_2$) is guaranteed, it is important to know how much phosphorus (P) or phosphoric acid (P_2O_5) it is equal to; and when potassium sulphate (K_2SO_4) only is guaranteed, we want to know how much potassium (K) or potash (K_2O), it is equal to. The data contained in Table 45 on the page following enable one easily and quickly to make the arithmetical calculation necessary:

To illustrate the use of the table, suppose, for example, we wish to change 10 pounds of ammonia into an equivalent amount of nitrogen; we multiply the amount of ammonia (10 pounds) by number found in last column opposite (1) in first column, which is 0.82, and the result is 8.2 pounds of nitrogen.

Or, suppose we wish to know how much phosphorus (P) there is in 10 pounds of phosphoric acid (P_2O_5); we multiply 10 by factor (16), which is 0.44, and the result is 4.4 pounds.

TABLE 45—FACTORS FOR SHOWING EQUIVALENT AMOUNTS OF EACH PLANT-FOOD CONSTITUENT IN DIFFERENT FORMS.

	To change		Multiply by
(1)	Ammonia	into an equivalent amount of nitrogen,	0.82
(2)	"	" " " " " sodium nitrate,	5.0
(3)	"	" " " " " ammonium sulphate,	3.9
(4)	Nitrogen	" " " " " ammonia,	1.2
(5)	"	" " " " " sodium nitrate,	6.0
(6)	"	" " " " " ammonium sulphate,	4.8
(7)	Sodium nitrate	" " " " " ammonia,	0.2
(8)	" "	" " " " " nitrogen,	0.165
(9)	" "	" " " " " ammonium sulphate,	1.55
(10)	Ammonium sulphate	" " " " " ammonia,	0.26
(11)	" "	" " " " " nitrogen,	0.21
(12)	" "	" " " " " sodium nitrate,	0.64
(13)	Potassium nitrate	" " " " " nitrogen,	0.14
(14)	Ammonium nitrate	" " " " " nitrogen,	0.35
(15)	Calcium cyanamid	" " " " " nitrogen,	0.35
(16)	Phosphoric acid	" " " " " phosphorus	0.44
(17)	" "	" " " " " "bone phosphate,"	2.2
(18)	"Bone phosphate"	" " " " " phosphorus,	0.2
(19)	" "	" " " " " phosphoric acid,	0.46
(20)	Phosphorus	" " " " " phosphoric acid,	2.3
(21)	"	" " " " " bone phosphate,	5.0
(22)	Potash	" " " " " potassium,	0.83
(23)	"	" " " " " potassium chloride,	1.6
(24)	"	" " " " " potassium sulphate	1.85
(25)	Potassium	" " " " " potash,	1.2
(26)	"	" " " " " potassium chloride,	1.9
(27)	"	" " " " " potassium sulphate,	2.2
(28)	Potassium chloride (muriate)	" " " " " potassium,	0.53
(29)	" " "	" " " " " potash,	0.63
(30)	Potassium sulphate	" " " " " potassium,	0.45
(31)	" "	" " " " " potash,	0.54
(32)	Potassium carbonate	" " " " " potash,	0.68

HIGH-GRADE AND LOW-GRADE FERTILIZERS

Commercial fertilizers vary greatly in respect to the percentages of nitrogen, phosphorus and potassium they contain. Those containing large amounts of these constituents are known as *high-grade,* while those containing small amounts are called *low-grade,* and between these are all possible gradations of composition. These terms are sometimes used also to indicate the availability of plant-food as, for example, sodium nitrate would be classed as a high-grade, and muck as a low-grade, fertilizer. As a rule, those plant-food materials that are most available also contain the largest amounts of plant-food,

as sodium nitrate, ammonium sulphate, etc.; while, on the other hand, those materials containing the least available forms of plant-food also contain it in small amounts, as muck, garbage-tankage, etc.

Cost of plant-food highest in low-grade fertilizers.— The writer made a careful study of the fertilizers sold in New York State during one year in order to ascertain the cost of plant-food in fertilizers containing different percentages. It was found that, of the brands of complete fertilizers sold, about 60 per cent. was of medium or low-grade. Since those grades are sold in much larger amounts, it is probably not far from the truth to say that of the total amount of goods sold fully 75 per cent. was of the lower grades, and probably not over 10 per cent. of strictly high grade.

Dividing fertilizers into four grades, the composition of each was shown to be as follows:

TABLE 46—COMPOSITION OF DIFFERENT GRADES OF FERTILIZERS

Class of fertilizers	In 100 pounds of fertilizer			
	Pounds of nitrogen	Pounds of available phosphoric acid	Pounds of potash	Pounds of total plant food
Low-grade	1.22	8.18 (3.6P)	2.60 (2.2K)	12.00
Medium-grade	1.70	9.10 (4.0P)	3.48 (2.9K)	14.28
Medium high-grade	2.47	8.82 (3.9P)	6.02 (5.0K)	17.37
High-grade	4.00	8.36 (3.7P)	7.22 (6.0K)	19.60

P, phosphorus. K, potassium.

While the percentage of available phosphoric acid does not vary greatly, the percentages of nitrogen and potash increase rapidly with each better grade and this is shown in the last column.

Taking up now the difference in cost of plant-food in high-grade and low-grade fertilizers, this can best be brought out by showing the cost of one pound of plant-

food as purchased by the consumer. The following table shows the average actual cost to purchasers of one pound of nitrogen, of available phosphoric acid, and of potash:

TABLE 47—AVERAGE COST OF ONE POUND OF PLANT-FOOD TO CONSUMERS

	Nitrogen. Cents	Available Phosphoric acid. Cents	Potash. Cents
Low-grade complete fertilizers	26.3	8.0 (18P)	6.8 (8.2K)
Medium-grade "	23.2	7.0 (16P)	6.0 (7.2K)
Medium high-grade "	21.0	6.4 (15P)	5.4 (6.5K)
High-grade "	19.6	6.0 (14P)	5.0 (6.0K)

P, phosphorus cost. K, potassium cost.

These figures show that the cost of one pound of plant-food of whatever kind is highest in the lowest-grade fertilizers and least in the highest grade.

The obvious conclusion is that the plant-food in the highest-grade fertilizers is cheapest to the purchaser. One ton of the low-grade fertilizer retailed at an average of $23, while one ton of the high-grade mixture sold at $32.80, but was a much more economical purchase at that price than was the low-grade material $10 lower. Another fact to be kept in mind is that in high-grade fertilizers the plant-food is apt to be in more available forms.

BRAND NAMES OF FERTILIZERS

Commercial fertilizers are commonly sold under special names or brands. Some names indicate that the fertilizer is intended for some special crop, such, for example, as "Complete manure for potatoes and vegetables," "Canner's special pea and bean fertilizer," "Hop and tobacco fertilizer," "Universal grain grower," "Grass and lawn top dressing," etc., etc.; others are simply fanciful names without any special significance and designed only to catch the imagination of buyers, as, for example, "New method fertilizer," "Farmer's reliable," "Harvest

favorite," "New rival," "Challenge crop grower," "Climax phosphate," "Farmer's friend," "Electric phosphate," "Excelsior guano," "Golden harvest," "Hustler," "Reliance," etc., etc. Some years ago, manufacturers of fertilizers offered for sale in New York State nearly 2,300 brands, but as soon as it was required by law to pay a license fee on each brand, the number at once dropped below 500.

Misleading names.—We have already (p. 274) called attention to the misuse of names in connection with acid phosphate, which is frequently sold under some brand stating or implying that it is dissolved bone. To illustrate farther, a so-called "natural fertilizer" now on the market contains, all told, about 0.75 per cent. of plant-food and none in easily available form; another, "Special for Lawns and Fruits," contains 0.52 per cent. as its total. Different brands of "Humus" fertilizers have appeared which are usually comparatively worthless. At one time ground phosphate rock ("floats") was sold extensively at $20 to $28 a ton under the name of "Natural Plant-Food." "Lava" fertilizers have also been exploited as highly valuable plant-foods; road dust is richer in plant-food and more economical in cost.

Misuse of names for special-crop fertilizers.—It has been stated above that in many cases the name of the fertilizer indicates that it is especially adapted for a particular crop. Taking a single state, which fairly represents conditions prevailing everywhere in the fertilizer trade, there were sold to farmers during one season between 40 and 50 brands that were, according to name, designed for the exact needs of potato crops. The composition was not alike in any two of these; the nitrogen varied from 0.8 to 4.94 per cent., the phosphoric acid from 4 to 10 per cent., and the potash from 2 to 10 per cent. The same chaotic condition prevails with reference to all the other special-crop fertilizers. The question can properly be asked: To what extent does a manufac-

turer of fertilizers really meet all possible conditions found where his goods are sold?

Proper method of using brand-names.—Several manufacturers have adopted the custom of using for a brand-name a combination of figures representing the composition, as, for example: "Five-Eight-Eight," "Four-Eight-Seven," "9-8-4," "2-9-5," etc. The first number stands for nitrogen, the second for available phosphoric acid and the third for potash. This is a safe, sensible and honest method; it states practically all that can be fully justified, so far as proportions of plant-food are concerned. The emphasis is placed on the composition, as it should be, and not on a name which usually means little or nothing.

MEANING AND USE OF COMMERCIAL VALUATION OF FERTILIZERS

The commercial valuation of a fertilizer or of any fertilizing material consists in estimating the approximate value or money-cost of the chief plant-food constituents (nitrogen, phosphorus and potassium) in one ton.

Retail cost and commercial valuation.—The chief factors that enter into the retail cost of fertilizers, or the price that the farmer pays, are the following: (1) Retail cash cost of unmixed materials (sodium nitrate, dried blood, acid phosphate, potassium chloride, sulphate, etc.); (2) cost of manufacture (mixing and bagging); (3) freight; (4) storage, commissions to agents and dealers, selling on long credit, losses by bad debts, etc. While these different factors enter into the total or retail cost, a commercial valuation includes only the first factor, viz., the retail cash cost of unmixed materials in the market. A commercial valuation, therefore, usually gives a figure considerably lower than the selling price of a fertilizer.

How a commercial valuation is made.—The percentage or number of pounds of each plant-food constituent in

100 pounds of fertilizer is multiplied by the number representing the price of one pound of each, and the results, added together, give the valuation for 100 pounds; this sum multiplied by 20 gives the valuation for one ton. For example, a fertilizer contains:

Per cent, or pounds per 100	Cents
2.5 of nitrogen at 15 cents a pound	37.5
5.0 of available phosphoric acid at 4 cents a pound	20.0
5.0 of potash at 5 cents a pound	25.0
Cost of constituents in 100 pounds	82.5
Total cost of constituents, or commercial valuation = 82.5 cents × 20 = $16.50	

Two questions at once suggest themselves: (1) How do we find the number of pounds of each constituent contained in 100 pounds of fertilizer? (2) How do we ascertain the price of a pound of nitrogen or of phosphoric acid, or of potash? We will now give the answers to these questions.

(1) *Finding number of pounds of a plant-food constituent in 100 pounds.*—For this purpose one must have the statement of analysis, either the figures given in the guarantee-analysis, or, preferably, the figures give in an official state analysis. The figure giving the per cent. is, of course, the number of pounds per 100.

(2) *Price of each constituent.*—This is obtained by consulting a price list, which is issued annually in most states by the experiment station or some state department; this list is commonly known as a "schedule of trade-values adopted by experiment stations." Below we give such a schedule adopted by the experiment stations of the Eastern and Middle states for the year 1911. The prices in this schedule represent the average prices at which, in the six months preceding March, the respective ingredients, in the form of unmixed materials, could be bought at retail for cash in Boston, New York, Philadelphia, etc. The figures usually represent wholesale prices plus about 20 per cent., except for available phosphoric acid. These prices represent approximately what the farmer would have to pay for the plant-food constituents if he were to buy them in unmixed

forms in Boston, or New York, or some other trade center. It must, of course, be kept in mind that these trade values are changing from time to time, especially for nitrogen; and, in making commercial valuations, one should obtain the latest schedules from the local experiment station.

TABLE 48—SCHEDULE OF TRADE-VALUES FOR PLANT-FOOD CONSTITUENTS FOR 1911

	Cents per pound
Nitrogen in ammonia salts	16
" " nitrates	16
Organic nitrogen in dry, fine-ground fish and blood	23
" " " cottonseed-meal and castor-pomace	21
" " " fine-ground* bone and tankage and mixed fertilizers	20
" " " coarse† bone and tankage	15
Phosphoric acid, soluble in water	4½
" " " " ammonium citrate (reverted)	4
" " in fine-ground fish, bone and tankage	4
" " " cottonseed-meal and castor-pomace	4
" " " coarse bone and tankage	3½
" " " mixed fertilizers, insoluble in water or ammonium citrate	2
Potash in high-grade sulphate, free from chloride (muriate) and in ashes	5
" " chloride (muriate)	4¼
" " cottonseed-meal and castor-pomace	5

*Fineness of particles less than one-fiftieth inch in diameter.
†Fineness of particles greater than one-fiftieth inch in diameter.

Rule for making valuation of fertilizers. Multiply the given per cent. of each constituent (nitrogen, phosphoric acid and *potash) by the corresponding schedule price, add the results and multiply the sum by 20.*

Example: What is the commercial valuation of one ton of a commercial fertilizer, having the guaranteed analysis indicated below?

	Per cent or pounds per 100		Trade-schedule price. Cents per lb		Valuation for 100 pounds. Cents
Nitrogen	2	×	20	=	40
Available phosphoric acid	8	×	4	=	32
Potash	3	×	5	=	15
Total valuation for 100 pounds					87

Total valuation for one ton or 2000 pounds = 87 cents × 20 = $17.40

Simple rule for making approximate valuation:

(1) Multiply the figure representing the per cent. of nitrogen by 4;

(2) Multiply the figure representing the per cent. of available phosphoric acid by 0.8;

(3) Multiply the figure representing the per cent. of potash by 1.0;

(4) Add the three results.

This rule assumes the nitrogen to be organic and the potash to be sulphate. If a considerable portion of the nitrogen is present in the fertilizer as nitrate or ammonium sulphate, and potash is in the form of chloride, the results by this rule are somewhat high. Correct results can be obtained for these materials by using the factors in the table given below to multiply the percentages by.

Using the same figures of analysis given in the example above, the operation of the rule is indicated as follows:

		Per cent.				
(1)	Nitrogen..................	2	×	4	=	8.0
(2)	Available phosphoric acid...	8	×	0.8	=	6.4
(3)	Potash	3	×	1.0	=	3.0
(4)	Sum, or commercial valuation...........					$17.40

While, at present schedule prices, the foregoing method gives good results, it would be less accurate if the schedule prices change. The method can be made more accurate for a large range of prices by making use of the following table:

TABLE 49—FACTORS TO USE IN MAKING VALUATIONS FOR VARYING SCHEDULE PRICES

Price per pound of plant-food constituent	Factor by which to multiply percentage	Price per pound of plant-food constituent	Factor by which to multiply percentage	Price per pound of plant-food constituent	Factor by which to multiply percentage
Cents		Cents		Cents	
2	0.4	6	1.2	15	3.0
2½	0.5	6½	1.3	16	3.2
3	0.6	7	1.4	17	3.4
3½	0.7	7½	1.5	18	3.6
4	0.8	8	1.6	19	3.8
4¼	0.85	9	1.8	20	4.0
4½	0.9	10	2.0	21	4.2
4¾	0.95	11	2.2	22	4.4
5	1.00	12	2.4	23	4.6
5¼	1.05	13	2.6	24	4.8
5½	1.10	14	2.8	25	5.0

The data in this table are used in the following manner: Consult the schedule of prices; then turn to the above table,

select the factor opposite the given price, and multiply this by the number giving the percentage of the constituent in the fertilizer. For example, when nitrogen in nitrate sells for 16 cents a pound, multiply the percentage of nitrogen by 3.2, which gives the commercial valuation of the nitrogen in one ton of the fertilizer. When nitrogen in any form costs 20 cents a pound, multiply the percentage by 4; the percentage of any constituent costing 10 cents a pound would be multiplied by 2; 5 cents a pound, by 1; 4 cents a pound, by 0.8, etc.

Valuations based on guarantees made in other than usual terms.—In considering methods of making valuations, we have assumed that guarantees are given in terms of nitrogen, phosphoric acid and potash. If, however, other terms are used, such as ammonia, bone phosphate of lime, sulphate of potash, etc., then it will be necessary to calculate the figures given in the guarantee into equivalent amounts of nitrogen, phosphoric acid or potash before going on with making the valuation. The method of calculating equivalent amounts is given in Table 45 (p. 460). The same table can be used for calculating the amounts of phosphorus equivalent to phosphoric acid, potash to potassium, etc.

Commercial value in relation to agricultural value of fertilizers.—The *agricultural value* of a fertilizer is measured by its *crop-producing power* from the standpoint of the farmer. The commercial value does not necessarily have any relation to crop-producing power. This is well illustrated in the case of nitrogen in dried blood, ground fish-scrap and sodium nitrate. According to commercial value at the present writing, a pound of nitrogen in fish-scrap costs 30 cents, in dried blood, 23 cents, and in nitrate, only 16 cents, whereas, in most cases, the nitrate nitrogen is of superior agricultural value. Again, a fertilizer containing large amounts of available phosphorus and a small amount of nitrogen, has a smaller money value than a fertilizer rich in nitrogen, and yet the phosphorus and not the nitrogen might

be the constituent that would be most profitable for a given farmer to purchase.

Use of commercial valuations.—When used with a proper understanding of its limitations, a commercial valuation is helpful as a means of comparing different fertilizers. It enables one to make a comparison on the basis of the selling price of a fertilizer and the commercial value of its unmixed constituents. This can be well illustrated in the four grades of fertilizers, the composition of which is given on page 461. Compared on the basis of selling price and valuation, these give the following results:

COMPARISON OF SELLING PRICE AND COMMERCIAL VALUATION

Class of fertilizer	Selling price per ton	Commercial valuation	Difference between selling price and valuation
Low-grade..............	$23.00	$14.58	$8.42
Medium-grade..........	24.85	18.12	6.73
Medium high-grade......	28.30	23.24	5.06
High-grade.............	32.80	30.02	2.78

In the low-grade fertilizer, the selling price is nearly $8.50 above the cost of the ingredients; the difference decreases as the fertilizer grows richer in plant-food constituents, until in the high-grade fertilizer, the selling price is only $2.78 above the cost of the constituents; expressed another way, the purchaser is getting a great deal more plant-food for his money in the high-grade fertilizer, each pound of plant-food costing less. *Generally speaking, those fertilizers are cheapest in which there is least difference between selling price and commercial valuation.*

While the comparative values are wholly commercial, they furnish valuable information, which is in most cases a safe guide. To be of greatest use, commercial valuations must be used and interpreted in connection with the composition, as given by the analysis. A choice between different fertilizers must not rest wholly on a comparison of valuation and selling price, but the composition of the fertilizer in

relation to the farmers' needs must be considered. For example, a fertilizer with a high percentage of nitrogen and low percentage of phosphoric acid would show a higher valuation than one low in nitrogen and high in phosphoric acid, and yet the phosphoric acid might be just the plant-food that would give best yields on a given field and crop.

One disadvantage connected with the use of commercial valuations is the fact that ordinary chemical analysis does not show the forms or sources of the materials; this really applies only to nitrogen and more particularly to the organic forms of nitrogen. Thus, when an analysis gives no information as to whether the nitrogen is from dried blood or ground leather or muck, a commercial valuation may be misleading to this extent. But in actual use it has been found that in a large majority of cases a commercial valuation is a safe guide in respect to the agricultural value when applied to different brands having the same general composition.

It is worth while for farmers to learn how to make commercial valuations and apply them before purchasing fertilizers; it will have a broadening and educating effect and will increase one's interest in, and intelligent appreciation of, the resemblances and differences existing between commercial fertilizers.

FERTILIZER LAWS

Those states in which commercial fertilizers are used in appreciable amounts have passed laws regulating their sale. This has been necessary as a matter of protection to farmers, for there are few commodities which offer so tempting a field for fraud; and it was the discovery of numerous cases of gross imposition that led to the passage of laws. While these laws vary somewhat in details, they are alike in essentials. At one time fertilizers were sold without any statement regarding their composition and a farmer was wholly unable by himself to know whether he was getting plant-food or useless dirt, and it was too costly to pay for a

chemical analysis. In this connection we will briefly notice: (1) The main provisions of fertilizer laws, (2) advantages of laws, (3) limitations and weaknesses.

Provisions of fertilizer laws.—The chief point of interest is the requirement of a guaranteed statement of analysis. Manufacturers are required to give a statement of chemical composition, guaranteeing the percentage of nitrogen (or ammonia), available phosphorus or phosphoric acid (total phosphorus or phosphoric acid in bone, tankage, etc.), and potassium or potash, contained in each brand offered for sale. This statement of composition is usually made on the bag or parcel containing the fertilizer. The enforcement of the law is usually in the hands of experiment stations, but in some states it is managed by a state department of agriculture which is under a commissioner or a board. Samples of the fertilizers sold in the state are collected annually, generally from goods in the hands of dealers and consumers. These samples are analyzed and the results published for free distribution.

Manufacturers are required to pay a tax which may be in the form of a license-fee for each brand offered for sale or in the form of a tax on each ton sold. The proceeds are used to pay the cost of carrying out the provisions of the law.

In some cases manufacturers are required to state the source and character of the materials contained in each fertilizer, a most desirable provision, while in others a statement is required if any inert nitrogenous matter like leather is used.

In some states legal prosecutions are instituted in those cases where any constituent is below the guarantee more than a certain amount, 0.50 per cent. for example. In most states, reliance for the protection of farmers is placed upon the effect of publicity in widely distributing the results of chemical analysis instead of upon legal prosecutions. It is the result of the writer's extended experience and observation that manufacturers whose goods are found deficient care very little for legal prosecution in comparison with the wide

publication among farmers of the fact of such deficiency. As compared with the results of publicity, the results of prosecutions are insignificant, not to mention the high cost, long delays, useless consumption of the time of chemists and others and the inevitable annoyance and general waste of energy accompanying lawsuits.

Advantages of fertilizer laws.—In general, fertilizer laws afford a large measure of protection to farmers, as well as to honest manufacturers. Fraudulent fertilizers are exposed and driven from the market. Careless or dishonest manufacturers suffer either temporary or complete loss of business. Larger amounts of high-grade plant-food materials are now used than formerly, as the result of legal inspection. There is greater uniformity in the composition of each brand of commercial fertilizers, owing to more effective means and care used in mixing. The number of different brands of fertilizers offered for sale, as well as the number of manufacturers in proportion to business, has been diminished. Of especial importance has been the value of the educational effect upon the many farmers who insist on seeing and studying the bulletins giving the official analyses of fertilizers before they make a purchase. The chemical analysis of a fertilizer, which was formerly meaningless to most farmers, is now appreciated to the extent, at least, of distinguishing nitrogen, available phosphoric acid or phosphorus and potash or potassium. The interest awakened by consulting bulletins of fertilizer analysis has led many farmers to study the different forms and uses of plant-food materials and this has served as an introduction leading to a desire for widened information relating to other details of crop-growing. Thus, the fertilizer bulletin has often proved a source of genuine, intellectual stimulation and this fact should not be underestimated.

Limitations of fertilizer laws.—The beneficial effects of the publication of fertilizer analyses can be of no direct value to farmers who fail to obtain or to use the bulletins giving the information. Legal requirements which do not

compel manufacturers to state the kinds and amounts of nitrogenous materials used, or chemical analysis which does not give as far as possible the different forms of these constituents, are not meeting their fullest extent of usefulness.

ADVANTAGES AND DISADVANTAGES OF COMMERCIAL FERTILIZERS

In closing our discussion of this important subject, we will briefly summarize some of the more important facts relating to the advantages and disadvantages that come from the use of commercial fertilizers.

Advantages of using commercial fertilizers.—Among the special advantages to be noticed are: (1) Convenience, (2) opportunity for choice, (3) uniformity, (4) completeness of mechanical mixture.

(1) *Convenience.*—Commercial fertilizers are widely distributed, are easily obtained, and can be purchased in any desired amount and at any convenient time.

(2) *Opportunity for choice.*—Fertilizers of different brands represent a great variety of proportions of plant-food constituents, among which one can generally find what he needs for his soil and crops, provided he has ascertained by experience what combination gives him best crop returns.

(3) *Uniformity.*—There is an advantage in being able to obtain the same mixture from year to year, when it best suits one's needs, and to feel assured of having the same kinds of plant-food materials in the same proportions. Generally speaking, the same brand of fertilizer, especially in case of the large manufacturers, has been found running very uniform from year to year. In some cases, manufacturers change the percentage of composition and retain the brand name, but, when this is done, it can be readily ascertained by comparing the fertilizer bulletin of one year with that of another. When, however, the plant-food material itself is changed, that is not usually perceptible to the farmer.

(4) *Completeness of mechanical mixture.*—It is possible

for manufacturers to prepare fertilizers so that they are evenly and thoroughly mixed, finely ground, dry, and in condition for convenient use. There are, however, some small manufacturers who through carelessness or inadequate machinery fail to make good mechanical mixtures, so that the plant-food constituents are not uniformly distributed, nor the materials sufficiently fine and dry. Fertilizers which are sent out when incompletely dry harden in the package before long and are extremely difficult to handle.

Disadvantages of using commercial fertilizers.—There are some definite disadvantages that accompany the exclusive use of commercial fertilizers, among which are (1) lack of knowledge of materials, (2) lack of economy, (3) lack of educational incentive.

(1) *Lack of knowledge of materials.*—Farmers are unable without help to know whether they are purchasing in a mixture the materials that are claimed to be present. So far as the guarantee-analysis gives information regarding the source of nitrogen, the farmer is purchasing blindly in most cases.

(2) *Lack of economy.*—In general, the most expensive way of purchasing plant-food is in the form of complete commercial fertilizers. Results of an investigation made by the writer showed that when nitrate nitrogen could be purchased by farmers at 14 cents a pound, the nitrogen in mixed fertilizers was costing over 20 cents a pound on an average, and, in the grades of fertilizers finding most extensive sale, the cost varied from 18 to 36 cents and similar disproportions were found in case of phosphorus and potassium.

(3) *Lack of educational incentive.*—The most serious disadvantage in the use of commercial fertilizers, as they are actually used in most cases, is that farmers are not stimulated to acquire needed information in regard to plant-foods and their proper use. Many farmers use commercial fertilizers blindly in somewhat the same way that people use patent medicines. In the hope of increasing yield of crops,

without definitely learning why crops are decreasing, commercial fertilizers are tried, some brand being used in accordance with the recommendation of a neighbor or some seller of fertilizers. It is easy to acquire the "fertilizer habit" and difficult to abandon it. This blind, slavish use of fertilizers deadens the intellectual activity and in many cases has led to actually decreased productivity of soil when sole dependence has been placed on their use for long-continued periods.

General reliability of commercial fertilizers.—In closing this chapter, it is only fair to say that it is the writer's belief, based on observation and experience derived from connection with fertilizer inspection for over twenty years, that the manufacture of commercial fertilizers today is, on the whole, more carefully managed, and the products more reliable in uniformity, than at any previous time.

CHAPTER XXV

HOME-MIXED FERTILIZERS

Commercial fertilizers are made of well-known materials, most of which can be purchased by any farmer. The question began to be raised some years ago as to why farmers could not purchase unmixed plant-food materials, such as sodium nitrate, ammonium sulphate, dried blood, ground fish, acid phosphate, ground bone, potassium chloride and sulphate, etc., and mix these materials for their own use. Several experiment stations have given careful attention to the study of home-made mixtures and have pronounced their use to be entirely satisfactory. Progressive farmers have followed the guidance of experiment stations. The number of farmers who mix their own fertilizers has increased from year to year. It has been noticed that when a farmer once tries this method, he rarely purchases a ready-mixed complete fertilizer afterwards.

Manufacturers of fertilizers and their agents have persistently sought to discourage the practice of home-mixing, but their statements cannot be accepted as the evidence of disinterested parties. It has been represented to farmers that peculiar and mysterious virtues are imparted to the plant-food constituents by proper mixing, and that really proper mixing can be accomplished only by means not at the command of farmers. Such statements are misrepresentations, based either upon the ignorance of the person who makes them or upon his determination to sell commercial mixed goods. Sodium nitrate, for example, does its work in plant nutrition in exactly the same manner whether it is added to the soil as part of a mixture or whether the ingredients are applied separately. The availability of plant-food is not usually affected by mixing, when proper precautions are taken not to mix certain kinds of materials together.

In presenting the subject of home-mixed fertilizers, we will discuss it under the following divisions:

1. Utensils needed to mix materials.
2. Method of mixing plant-food materials.
3. Use of fillers and driers.
4. Purchasing unmixed materials.
5. Materials that should not be mixed together.
6. Advantages and disadvantages of home-mixing.
7. Co-operative purchase of unmixed and mixed fertilizers.
8. How to calculate amounts of materials for home-made mixtures.

UTENSILS NEEDED IN MIXING MATERIALS

The conveniences needed to mix fertilizers on the farm are the following: (1) A tight floor, hard, dry and under shelter, (2) platform scales, (3) a shovel, (4) iron hand-rake or hoe, (5) a tamper to break hard lumps, (6) a sand or coal-screen, (7) a grinding-machine, and (8) a mixing-machine. A few of these conveniences call for special attention.

(1) *The tamper* can be made by nailing two upright handles to a piece of wood 6 inches thick and 15 to 18 inches long. If one has a good grinding-machine, breaking of coarse lumps by pounding may not be necessary.

(2) *The screen* can be 5 to 6 feet long, 1½ to 2½ feet wide, with 3 to 6 meshes to the inch.

(3) *Grinding-machine.*—For making coarse material finer, a good feed-grinding mill will answer. Where one has power on the farm and mixes large amounts of fertilizing materials, it will pay to purchase a special grinding-machine; some are now on the market that will grind limestone fine. The principal use of a grinding-machine is to pulverize such materials as sodium nitrate, ammonium sulphate, potassium compounds, etc. These materials have all been ground

once, but become lumpy on standing and are easily broken up by being passed through a feed-mill that is regulated so as to permit wheat to pass. For lumps of acid phosphate, such a mill should be set so as to crack corn but not wheat.

IMPLEMENTS FOR HOME MIXING

If one tries to grind acid phosphate, ground tankage or fish-scrap, the material is likely to become sticky and unmanageable; this trouble can be avoided by setting the feed-mill sufficiently open to disintegrate lumps without grinding the material.

(4) *Mixing-machine.*—While mixing can be done by shoveling the materials over and over, it will be found easier to use some kind of a rotating box. A large, revolving churn with slats across the inside can be used, or a box or drum with small projecting shelves on the inside, which carry the materials around to the top and then drop them from the upper half to the bottom to be taken up by shelves and carried around again and dropped repeatedly.

Method of mixing materials.—The various operations in mixing fertilizing materials are the following: (1) Weighing materials, (2) screening out lumps, (3) crushing lumps, (4) mixing, (5) storing.

(1) *Weighing materials.*—The first operation is to weigh out the desired amount of each material; the method of calculating amounts of materials will be considered later (pp. 491-497).

(2) *Removing lumps.*—If any material is lumpy, it is sifted through the sand-screen and the coarse portions separated. The driest material is screened last. Screens should be kept clean.

(3) *Crushing lumps.*—The lumpy portion is made fine by use of a tamper or a shovel, or preferably by passing through a grinding-machine, as explained in the preceding section, the driest material being ground last. The powdered lumps are added to the screened portion. The mill should always be cleaned at once after using. It may be stated that lumpy sodium nitrate easily disintegrates when it is sprinkled lightly with water, allowed to stand some hours and then raked over.

(4) *Mixing.*—When the materials are in proper condition of fineness, they are ready for mixing. When a mixing-machine is not used, the most bulky material, usually that containing phosphorus, is spread out upon the floor in a uniform layer about 6 inches deep; upon this is spread evenly the material next in bulk, usually that containing nitrogen; and then the least bulky material, generally that

containing potassium. Care is taken to make the material in each case cover the one under it evenly over the whole surface. Beginning at one side and working across, one should shovel the whole pile over, making the shovel reach clear to the bottom of the pile every time. When the whole pile has been carefully shoveled over once in this way, the mixed pile is leveled, the scattered material about the edges swept to the pile and the whole is again shoveled over. This process should be repeated three or four times or until thoroughly mixed, as shown by uniformity of color and absence of streaks of different materials. The mixture can finally be passed through the screen once, if desired.

When a mixing-machine is used, like that described above, the different materials in proper amounts, when ready for mixing, are put into the mixing-machine, the door closed and the machine rotated for some minutes. The amount mixed in a machine depends chiefly on the size of the mixer. Care should be taken never to fill such mixers more than half full; otherwise the mixing may not be thorough.

(5) *Storing.*—For storage and general convenience in handling, it is well to weigh the mixed fertilizer into sacks that hold 100 to 150 pounds.

USE OF FILLERS AND DRIERS

There is a popular belief that all fertilizers contain some inert, valueless material added solely for the purpose of making weight. While this may be true in some cases it is not necessarily true in most fertilizers. This belief in the universal use of fillers in fertilizers is based upon the methods of stating the results of chemical analysis. For example, a high-grade fertilizer, showing an analysis of 5 per cent. of nitrogen, 10 of phosphoric acid (equal to 4.4 phosphorus) and 10 of potash (equal to 8.3 potassium), contains, all told, only 25 pounds of plant-food constituents in 100 pounds of material, or, using the figures for phosphorus and potassium, only 17.7 pounds of plant-food constituents. Many raise the

question as to what the remainder of 75 pounds consists of, assuming it to be worthless filler added to increase weight. This seeming difficulty is easily explained when we consider that the method of stating the results of chemical analysis gives only a part of what is in the fertilizer. For example, nitrogen is present in fertilizers only in combination with other elements; in sodium nitrate, for each pound of nitrogen used, we add to a fertilizer about 1.5 pounds of sodium and 3.5 pounds of oxygen; or, expressed in another way, sodium nitrate consists of only one-sixth nitrogen and, in order to get one pound of nitrogen, it is necessary to use 6 pounds of sodium nitrate. Similarly, it requires about 10 pounds of dried blood to furnish one pound of nitrogen, etc. (p. 254). Each material used is a compound or diluted form of nitrogen, phosphorus or potassium. For a variety of reasons it is impossible to use either pure nitrogen, phosphorus or potassium in fertilizers, and we must use those compounds or diluted forms which are best adapted to feeding plants and at the same time are sufficiently plentiful and cheap to make their use practicable. These statements will find constant illustration later and we do not need to enlarge upon them here.

While worthless materials may be added as fillers to make low-grade fertilizers, there is also a legitimate use of so-called fillers, and that is as driers for the special purpose of insuring good mechanical condition. Materials like sodium nitrate, calcium nitrate, potassium chloride, kainite, etc., absorb moisture and the mixtures in which such materials are present are liable to harden on standing. This can be prevented by using in the mixture some dry, inert material that will hold moisture and keep the mass from caking. For this purpose nothing is better than *fine, dry muck* or *peat*. One can also use *fine sand, gypsum, coal ashes, fine cinders, sawdust* and even *fine, dry earth*. It will not, however, do to use quicklime (calcium oxide) or slaked lime (calcium hydroxide) or wood-ashes in many ferti-

lizers (p. 485). When a mixture contains considerable amounts of bone-meal, fine tankage or cottonseed-meal, no filler or drier will usually be needed, since these materials generally insure a good mechanical condition. When a home-mixed fertilizer is prepared some weeks or months before it is used, and especially when it contains considerable amounts of sodium nitrate and potassium chloride, it will usually be well to put into the mixture some material to act as a drier to prevent hardening into a cake.

PURCHASING UNMIXED MATERIALS

In purchasing unmixed materials, attention should be given to certain points which have often been the subject of inquiry among farmers. Some of the more important of these that deserve our consideration are the following: (1) Where to purchase, (2) how, (3) when, (4) what grade, (5) co-operative buying, (6) use of "unit" system, (7) fineness and dryness.

Where to purchase unmixed materials.—Experiment stations in the different states usually furnish on request a list of the addresses of reliable dealers in plant-food materials. Many, if not most, manufacturers of fertilizers do not handle this kind of trade. Special dealers in sodium nitrate are located in commercial centers throughout the United States, and many of these also make a specialty of handling other unmixed materials. Owing to the increasing demand for these goods, local dealers are increasing in number in localities where fertilizers are extensively used.

How to purchase unmixed materials.—Before purchasing, farmers are advised to obtain for themselves prices at which they can actually buy plant-food. Quotations should be obtained by making inquiries from three or four different sellers, asking at what prices they will furnish the specific forms of plant-food materials that one wishes to use. This precaution will prevent the possibility of paying a price

above that prevailing at the time. Usually, however, the quotations will be found practically the same.

When to purchase materials.—By watching market variations as they are now reported in agricultural papers, it is possible to save something. It often happens that the lowest prices prevail in early winter, a season when farmers are the least busy. On all accounts, this will be found the best time to buy and mix materials, since home-mixing should be completed before the beginning of spring work. It is well to begin correspondence about the purchase of materials in November or December.

What grade of materials to buy.—It will invariably be found more economical to purchase high-grade plant-food materials. While bulk is often desirable in applying fertilizers, the object in purchasing should be to obtain as much available nitrogen, phosphorus and potassium as possible for one dollar, instead of as many pounds as possible of material, regardless of the amount of plant-food contained in it. This statement applies to all fertilizers, mixed or unmixed.

Co-operative buying.—In purchasing unmixed plant-food materials, considerable economy can be effected by the combination of several farmers in a community in ordering their supplies together. This method is being advantageously used by many granges and farmers' clubs. The unmixed materials are purchased in quantity and distributed to individuals, each of whom mixes his own materials. This method effects saving of freight and obtains the benefit of lower prices on carload lots. Such methods always depend upon cash payment and usually result in the most economical purchase of plant-food possible.

Use of "unit" system in purchasing materials.—The method that has been commonly employed by farmers, and is still too much, in purchasing fertilizers, whether mixed or unmixed, is to pay a given price for a ton of material without particular reference to its guaranteed composition, which tells how much plant-food there is. In purchasing

such high-grade materials as sodium nitrate, ammonium sulphate, potassium compounds, etc., the composition is fairly uniform and one may generally be safe in purchasing by the ton. However, in variable material like tankage, for example, one should never purchase without a guaranteed statement of composition.

The "unit" system is based on actual amounts of plant-food contained in the materials purchased. A unit of plant-food is one per cent. for one ton, that is, 20 pounds. A unit of nitrogen, or available phosphoric acid, or potassium, is 20 pounds. In quoting prices, a dealer might offer potassium sulphate at $1 per unit of actual potash, 20 pounds of potash, which would equal 5 cents a pound. Of course, we can get at the same result on a ton basis and a specific percentage guarantee. For example, potassium sulphate containing 50 per cent. of potash is quoted at $50 a ton; 50 per cent. of a ton is 1,000 pounds, and a pound costs 5 cents. The unit system is somewhat simpler, because, to find out the price of one pound, it is necessary only to divide the price of one unit by 20.

Fineness and dryness important.—Materials to be used in mixing should be in finely powdered form and dry. This is necessary in order that the materials may be more easily and completely mixed and that the mixture be in good mechanical condition for applying to the soil. Usually, unmixed materials that have stood for some time cake more or less and will need screening and grinding before mixing. The precaution should be taken to keep unmixed materials stored in a dry place before mixing, and, of course, the mixed materials should likewise be kept dry to prevent caking, as well as possible loss of organic nitrogen through decomposition.

MATERIALS THAT SHOULD NOT BE MIXED TOGETHER

Plant-food materials cannot be mixed indiscriminately without, in some cases, incurring risk of loss or unfavorably

affecting the mechanical condition. It is important to know what mixtures should not be attempted, and we present here a comprehensive statement regarding the subject, including most of the materials with which a farmer may have to do. We will state the facts under the following heads: (1) Loss of ammonia nitrogen, (2) loss of nitrate nitrogen, (3) reversion of soluble phosphoric acid, (4) unfavorable mechanical effect.

Mixtures causing loss of ammonia nitrogen.—Alkaline compounds easily set free ammonia from ammonium compounds, such as ammonium sulphate. They may also, if in sufficiently concentrated form, decompose animal matter, setting free ammonia, especially when stored in a damp, warm place. When mixtures of such materials are immediately placed in the soil, the ammonia is held (p. 182), but when they stand in the air, the ammonia escapes and is lost. The following list indicates materials that should not be mixed for this reason:

Calcium oxide (quicklime) Calcium hydroxide (slaked lime) Potassium carbonate (in wood-ashes) Basic-slag phosphate Calcium cyanamid Basic calcium nitrate	Should not be mixed with	Ammonium sulphate Animal manures (bone, tankage, blood, fish scrap, etc. Nitrogenous guanos

It is claimed that the preparations of calcium cyanamid now in use overcome this objection.

Loss of nitrate nitrogen.—There is one condition under which loss of nitrate nitrogen is liable to occur, though it is probably not frequent, but should be mentioned as a possibility. When moist acid phosphate, so carelessly made as to contain considerable amounts of free sulphuric acid, is mixed with sodium nitrate and kept in a warm place, some free nitric acid may be formed and escape into the air. Any such possibility of loss can be obviated by adding to the materials before mixing a little sprinkling of finely powdered slaked lime or carbonate, which will neutralize any sulphuric

acid present. Care should be taken not to add too much, since the soluble phosphate would be reverted.

Reversion of soluble phosphoric acid.—When certain calcium compounds are mixed with soluble calcium phosphate, as contained in acid phosphate or any superphosphate, the soluble phosphate is changed to the reverted form (p. 46). The following form of statement indicates what mixtures are to be avoided on this account:

Calcium oxide........ Calcium hydroxide.... Calcium carbonate.... Wood-ashes.......... Basic calcium nitrate..	Should not be mixed with	Soluble phosphates (superphosphate, acid phosphate, etc.)

For the same reason magnesium, iron and aluminum compounds should not be mixed with acid superphosphates, but these materials do not occur in appreciable amounts in most plant-food materials.

Unfavorable mechanical effect.—Several of the materials used in making fertilizers have more or less of a tendency to absorb moisture, such as sodium nitrate, potassium chloride, kainite, and other crude potash materials. When calcium compounds, like quicklime or slaked-lime, are mixed with such moisture-absorbing materials, they are likely, on standing for some time, to harden and make a solid mass, difficult to handle. If, however, the mixture is distributed soon after being made, this trouble is avoided. Another method of preventing the occurrence of hardening in such cases is to add to the mixture one-fourth or more of its weight of fine, dry muck, or some similar good drier. The materials which for this reason should not be mixed, or mixed only just before using on the soil, are indicated in the following way:

Calcium oxide (quicklime)...... Calcium hydroxide (slaked lime) Basic calcium nitrate..........	Should not be mixed with, except just before application to soil	Sodium nitrate Potassium chloride Kainite, etc.

ADVANTAGES AND DISADVANTAGES OF HOME-MIXING

Some of the advantages of home-mixed fertilizers have been incidentally indicated in a general way, but it is desirable that we should consider both sides of the subject, the unfavorable as well as the favorable aspects, in order to reach a sound basis of judgment.

Advantages of home-mixing.—Among the specific advantages that may result from purchasing unmixed materials and mixing them on the farm, we will notice the following: (1) Economy, (2) definite knowledge of materials used, (3) variation of mixtures to suit different conditions, (4) educational value.

(1) *Economy in home-mixed fertilizers.*—The average retail price of one ton of a mixed commercial fertilizer is, as previously stated (p. 469), considerably higher than the retail cost of the unmixed materials. This difference, which represents the cost of mixing, freight, profit, commissions, etc., varies according to the grade of fertilizer; in the case of high-grade goods, the difference averages only about $5, while in low-grade fertilizers the difference averages $8 or $9. It is obvious that at least a considerable portion of this difference can be saved by purchasing unmixed ingredients. The following figures illustrate differences that have been found to exist in the cost of a pound of plant-food in mixed fertilizers and unmixed materials:

TABLE 50—AVERAGE COST OF ONE POUND OF PLANT-FOOD IN MIXED AND UNMIXED FERTILIZERS

	Nitrogen. Cents	Available phosphoric acid. Cents	Potash. Cents
COMMERCIAL FERTILIZERS			
Low-grade complete fertilizers	26.3	8.0	6.8
Medium-grade	23.2	7.0	6.0
Medium high-grade	21.0	6.4	5.4
High-grade	19.6	6.0	5.0
UNMIXED MATERIALS			
Dried blood	18.5	—	—
Bone-meal	14.9	4.0 (total phos. acid)	
Sodium nitrate	13.9	—	—
Acid phosphate	—	5.1	—
Potassium sulphate	—	—	5.0
Potassium chloride	—	—	4.6

The cost of a pound of plant-food in unmixed materials is markedly lower than even in high-grade mixed fertilizers, the difference becoming greater as the grade of the commercial fertilizers goes down.

In addition to the cost of materials, farmers can properly add the cost of their labor in mixing, which is in reality a small matter, since this work can be done when there is least demand on the farmer's time. For the farmer who purchases low-grade mixed commercial fertilizers, there is a possible saving of $10 a ton, and it is safe to count on $5 at least. For those who purchase high-grade fertilizers, the saving will usually be $5 or more a ton, and not less than $3. For those who use 10 tons or more of fertilizer, the saving effected by home-mixing can be seen to be very considerable in the aggregate.

(2) *Definite knowledge of materials used.*—When separate materials are purchased, the farmer can more easily ascertain whether they are what they are purchased for. Ground leather cannot be passed off for sodium nitrate or ammonium sulphate. In mixed goods, all mysteries of inferior composition are beyond detection by the eye. Unmixed materials are usually more uniform in composition than the mixed. The chances are that the farmer will get better forms of plant-food in unmixed than in mixed products.

(3) *Variation of conditions to suit different needs.*—By careful observation and some experimenting, each farmer can make mixtures with those proportions of plant-foods which best meet the conditions of his soil and crops. It is safe to say that, without any experience, farmers can hit their needs by mere guessing quite as nearly as do some of the complete fertilizers that they use. Attention has already (p. 463) been called to the fact that among mixed fertilizers special mixtures for the same crop are found to vary quite as much as do mixtures for different crops. In purchasing unmixed materials, one can apply a single plant-food con-

stituent at a time, a method that is found very useful under some conditions.

(4) *Educational value.*—There is little of educational value in using an unknown mixture. To purchase intelligently unmixed fertilizing materials ultimately leads in most cases to a well-grounded knowledge of agricultural science. One will seek to know what the different forms of plant-food materials are, what they do, from what sources they are derived, how they can be obtained and how he can use them to best advantage. He becomes a student and an investigator and, of necessity, takes a deeper interest in his work. His entire system of farming is lifted to a higher plane and his more intelligently applied labor yields more profitable results. The writer has had opportunity to observe many such cases of evolution.

Disadvantages of home-mixing.—The disadvantages that are suggested in connection with home-mixing are the following: (1) Difficulty of purchasing small amounts of unmixed materials, (2) injury to crops from incomplete mixing, (3) imperfect mechanical condition, (4) injury to crops by application of concentrated materials.

(1) *Difficulty of purchasing small amounts of unmixed materials.*—It has been true, but is no longer, that it is difficult to obtain small lots of unmixed materials; for dealers are rapidly increasing and are ready to sell materials in small or large amounts. The advantage of purchasing large amounts can readily be realized by co-operation of farmers in purchasing their supplies together.

(2) *Injury to crops from incomplete mixing.*—Farmers are told by sellers of mixed fertilizers about the difficulty of mixing fertilizing materials, with the consequence of uneven application to the soil, some portions getting little or no plant-food and others too much, the result of which makes uneven crops and reduced yields. As to the ability of farmers to mix their own fertilizers, no doubt exists except in the minds of those who desire to sell mixed goods. The

fact that a farmer who once intelligently undertakes mixing his own fertilizers seldom goes back to the use of commercial mixed fertilizers is sufficient evidence of accomplished success. The number of farmers engaged in the home-mixing of fertilizers is constantly increasing, in spite of discouragement promoted by sellers of mixed fertilizers.

(3) *Imperfect mechanical condition.*—While it is true in the best-made commercial fertilizers that the degree of fineness is better than in home-mixed materials, home-made mixtures can, with the precautions given, be made sufficiently fine for all practical purposes and fully as satisfactory as that found in many mixed fertilizers and much better than that found in some coming under the observation of the writer.

(4) *Injury to crops by application of concentrated materials.*—When materials like sodium nitrate, acid phosphate and potassium chloride or sulphate are put together, we have a mixture of concentrated materials, which may do harm to seeds when the mixture is applied to the soil. It requires some care to spread concentrated mixtures evenly, and in amounts too small to injure seeds. This difficulty is easily overcome by mixing with the concentrated materials more or less inert matter like fine, dry muck, sand, earth, etc.

CO-OPERATIVE PURCHASE OF FERTILIZERS

In some towns, farmers combine in the purchase of unmixed plant-food materials, each one doing his own mixing. In other cases, a farmers' organization decides upon one or more definite formulas and sends out specifications to manufacturers for furnishing the same ready mixed and sacked, letting the contract to the lowest responsible bidder. For example, in one community, where potatoes and vegetables are exclusively grown, they have found that they obtain increased crop returns by the use of a fertilizer containing 4 per cent. of nitrogen, 8 per cent. of available phos-

phoric acid and 10 per cent. or less of potash. They require the nitrogen to be furnished in three different forms, one-half in ground fish, one-fourth in sodium nitrate and one-fourth in ammonium sulphate; the potash is in the form of chloride. One season they purchased 1,000 tons of this mixture at $24.80 a ton; commercial fertilizers of the same composition were retailing at the same time for $36 to $40. The actual saving effected by the members of this organization was not less than $10,000 a year. At the stated price, nitrogen cost 11.7 cents a pound, phosphoric acid 3.6 cents and potash 3.75 cents, prices a little over one-half those paid for plant-food by the average farmer purchasing mixed fertilizers in the ordinary way.

HOW TO CALCULATE AMOUNTS OF MATERIALS FOR HOME-MADE MIXTURES

Many communications come to the writer from farmers, asking him to calculate the amounts of materials to be used in making a fertilizer according to a given formula or certain proportions of nitrogen, phosphoric acid and potash. We will now give methods which can be used by anyone who is at all familiar with ordinary processes of arithmetic. We will first give the usual method of making the necessary calculations, and later (p. 494) will give a much shorter and simpler method which is equally accurate when one knows the composition of the materials one uses.

For example, a farmer wishes to make a fertilizer containing:

3.5 per cent of nitrogen
8.0 " " " available phosphoric acid
10.0 " " " potash

and for this purpose he has the following materials:

Sodium nitrate containing 15 per cent. of nitrogen
Acid phosphate containing 14 per cent. of available phosphoric acid
Potassium chloride, containing 50 per cent. of potash

How much of each of these materials is it necessary to

take to make one ton of a mixture having the above percentage composition?

The process necessary to solve the problem may be conveniently divided into four steps or operations, as follows:

(1) The first step consists in finding the number of pounds of nitrogen, phosphoric acid and potash in one ton of a fertilizer having the formula given above (3.5—8—10). This is done by multiplying the number representing the per cent. by 20, as follows:

	Per cent. (pounds per 100)				Pounds per ton
Nitrogen....................	3.5	×	20	=	70
Available phosphoric acid....	8.0	×	20	=	160
Potash.....................	10.0	×	20	=	200

(2) The second step consists in finding (a) how many pounds of sodium nitrate containing 15 per cent. of nitrogen will be required to furnish 70 pounds of nitrogen; (b) how many pounds of acid phosphate containing 14 per cent. of available phosphoric will be required to furnish 160 pounds of available phosphoric acid; and (c) how many pounds of potassium chloride containing 50 per cent. of potash will be required to furnish 200 pounds of potash.

(a) Since 100 pounds of sodium nitrate contains 15 pounds of nitrogen, it will require to furnish 70 pounds of nitrogen as many times 100 as 15 is contained in 70, or 460; this calculation may be represented as follows: $70 \div 15 \times 100$ or $\frac{70 \times 100}{15} = 460$ pounds of sodium nitrate.

(b) Since 100 pounds of acid phosphate contains 14 pounds of available phosphoric acid, it will require to furnish 160 pounds of available phosphoric acid as many times 100 as 14 is contained in 160; $160 \div 14 \times 100$, or $\frac{160 \times 100}{14} =$ 1140 pounds of acid phosphate.

(c) Since 100 pounds of potassium chloride contains 50 per cent. of potash, it will require to furnish 200 pounds of potash as many times 100 as 50 is contained in 200; $200 \div 50 \times 100$, or $\frac{200 \times 100}{50} = 400$ pounds of potassium chloride.

(3) The third step consists in adding the amounts of plant-food materials (460+1140+400), which equal 2,000 pounds.

In case the added materials fall short of 2,000 pounds, as often happens, enough inert material or filler or drier (p. 480) is added to make the total mixture equal 2,000 pounds. For example, a 3—8—7 mixture made up from the same materials as those used in the illustration would make 1,800 pounds (400+1120+280); to make this to an even ton, we add 200 pounds of fine, dry muck or peat, or sand or fine earth, etc.

We can now state the method of operation in the form of a rule.

Finding amounts of materials to use in making fertilizers.—*Rule.* To find the amount of each material to use in making one ton of a fertilizer, having a given percentage composition, when the different materials are given with the percentages of plant-food constituents each contains, proceed as follows:

(1) *Find the number of pounds of nitrogen, available phosphoric acid and potash contained in one ton of the mixture by multiplying in each case, respectively, the number giving the per cent. by 20.*

(a) Per cent. nitrogen × 20 = pounds of nitrogen in one ton of fertilizer
(b) " " phosphoric acid × 20 = " " phosphoric acid " " " " "
(c) " " potash × 20 = " " potash " " " " "

(2) *Find the number of pounds of given material required to furnish the number of pounds of each plant-food constituent in one ton of mixture, as follows: Multiply by 100 the number of pounds of each plant-food constituent contained in a ton and divide the result by the number giving the percentage of the respective plant-food constituent in the material used.*

(a) Lbs nitrogen in 1 ton × 100 ÷ % nitrogen in material used = Lbs nitrogen material required
(b) " phos. acid in 1 ton × 100 ÷ % phos. acid in material used = Lbs. phos. acid material required
(c) " potash in 1 ton × 100 ÷ % potash in material used = Lbs. potash material required

(3) *Find the total amount of plant-food materials by adding together the results obtained in the preceding step. If the sum is less than 2,000, add enough fine, dry muck or other inert material to make 2,000 pounds.*

Calculation of materials based on acre application.—Suppose a farmer is instructed to apply per acre 30 pounds of nitrogen, 70 pounds of available phosphoric acid and 50 pounds of potash, in the form of sodium nitrate, acid phosphate and potassium chloride, containing the usual percentages (15 of nitrogen, 14 of available phosphoric acid and 50 of potash), how can he find out how much of each material it will be necessary to use? This practically involves only the second step in the preceding process. The operation is indicated briefly, as follows:

(a) 30 (lbs nitrogen) × 100 ÷ 15 (% nitrogen in nitrate) = 200 lbs of sodium nitrate
(b) 70 (lbs. phos. acid) × 100 ÷ 14 (% phos. acid in acid phos.) = 500 lbs. of acid phosphate
(c) 50 (lbs potash) × 100 ÷ 50 (% potash in chloride) = 100 lbs of potassium chloride

The results added together would make an application of 800 pounds of the mixture per acre. In such a case as this, if one desired to make larger amounts, each material is increased two, three, or as many times as suits one's purpose or convenience.

Short method for calculation of amounts of materials.—By making use of the figures given in Table 51, considerable labor can be saved, especially when one knows the percentage of plant-food constituents in the materials he uses. The use of the figures in the table can best be understood by giving an example. Suppose one wishes to make a mixture like the one already given (p. 492) as an illustration (3.5—8—10), using the same materials (nitrate with 15 per cent. of nitrogen, acid phosphate with 14 per cent. of phosphoric acid, and potassium chloride, with 50 per cent. of potash). To find how much sodium nitrate to use, we look down the percentage column in Table 51 until we come to 15 and see opposite it the number 133; we then multiply this by 3.5, the per cent. of nitrogen that the mixture is to contain. For the 14

per cent. phosphoric acid in acid phosphate, we find 143, and multiply this by 8, the per cent. of phosphoric acid in the mixture; and for 50 per cent. of potash we find 40, which we multiply by 10, the per cent. of potash in the mixed fertilizer. The operations are indicated as follows:

Plant-food constituent	Per cent in mixed fertilizer		Factors found in table		Amount of materials to use
Nitrogen..................	3.5	×	133	=	460 pounds of sodium nitrate
Phosphoric acid	8.0	×	143	=	1140 " acid phosphate
Potash	10.0	×	40	=	400 " potassium chloride
Total material					2000

TABLE 51—FACTORS FOR QUICK CALCULATION OF AMOUNTS OF MATERIALS TO USE IN MIXING FERTILIZERS

Per cent. of plant-food constituent in material used	Factor to use in multiplying	Per cent of plant-food constituent in material used	Factor to use in multiplying	Per cent of plant-food constituent in material used	Factor to use in multiplying	Per cent of plant-food constituent in material used	Factor to use in multiplying
1	2000	6½	308	12	167	17½	114
1½	1333	7	286	12½	160	18	111
2	1000	7½	267	13	154	18½	108
2½	800	8	250	13½	148	19	105
3	667	8½	235	14	143	19½	100
3½	570	9	222	14½	138	20	10
4	500	9½	210	15	133	25	80
4	444	10	200	15½	129	40	50
5	400	10½	190	16	125	48	42
5½	364	11	182	16½	121	49	41
6	333	11½	174	17	118	50	40

We will furnish some additional illustrations of use of the table. (1) How much dried blood containing 12 per cent. of nitrogen should be used to furnish nitrogen for one ton of a fertilizer containing 3 per cent. of nitrogen? Opposite 12 (per cent. column) we find the factor 167, which, multiplied by 3, gives 500 pounds as the amount of dried blood to use. (2) How much acid phosphate, containing 14½ per cent. of available phosphoric acid, must be used to furnish phosphorus for one ton of a fertilizer containing 10 per cent. of phosphoric acid? Opposite the figure 14½ we find 138, which multiplied by 10, gives 1,380 pounds of acid phosphate.

(3) How much kainite, containing 12½ per cent. of potash, should be used to furnish potassium in a fertilizer containing 5 per cent. of potash? Opposite 12½ we find the factor 160, which, multiplied by 5, equals 800 pounds of kainite.

Calculations to make when composition is stated in other than usual terms.—We have assumed in our previous discussion that the composition of materials is stated in terms of nitrogen, available phosphoric acid and potash. If, however, the guarantee of nitrogen is given as ammonia, the amount of nitrogen can be easily calculated by consulting Table 45 (p. 460). And, similarly, if other changes are to be made to get the amounts of plant-food in terms of nitrogen, phosphoric acid, phosphorus, potash or potassium, the method of making the needed calculation can be found in Table 45 and in pages preceding (pp. 452-460). In most cases, however, guarantees will be in usual form.

Amount of material containing one pound of plant-food.—It is often a matter of convenience to know without making detailed calculations how many pounds of fertilizing material are required to furnish one pound of plant-food (nitrogen, phosphorus or phosphoric acid, and potassium or potash). In the following table there is given in one column the percentage of plant-food in the fertilizing material, and in the next column the number of pounds of such material required to furnish one pound of plant-food.

Table 52—Amount of Fertilizing Material Containing One Pound of Plant-Food

Per cent. of plant-food constituent in material	Pounds of material required to furnish one pound of plant-food	Per cent. of plant-food constituent in material	Pounds of material required to furnish one pound of plant-food	Per cent. of plant-food constituent in material	Pounds of material required to furnish one pound of plant-food
1	100	9	11.1	17	6.0
2	50	10	10.0	18	5.5
3	33	11	9.0	19	5.3
4	25	12	8.3	20	5.0
5	20	13	7.7	25	4.0
6	16.7	14	7.2	40	2.5
7	14.3	15	6.6	48	2.1
8	12.5	16	6.2	50	2.0

To illustrate how the table may be used, the following illustrations are given: (1) How many pounds of bone-meal containing 4 per cent. of nitrogen will be required to furnish 1 pound of nitrogen? Ans.—25 pounds. (2) How many pounds of cottonseed-meal containing 7 per cent. of nitrogen will be required to furnish 1 pound of nitrogen? Ans.—14.3 pounds. (3) How many pounds of kainite containing 12 per cent. of potash will furnish 1 pound of potash? Ans.—8.3 pounds. (4) How many pounds of acid phosphate containing 14 per cent. of available phosphoric acid will furnish 1 pound of available phosphoric acid? Ans.—7.2 pounds.

CHAPTER XXVI

ROTATION OF CROPS

The artificial factors of crop production are, as previously stated (p. 399), tillage, crop-rotation and application of plant-food materials or fertilizers. The relations of tillage were discussed in Part I (p. 153). Crop-rotation and the use of fertilizers are intimately connected and we have therefore reserved our discussion of crop-rotation as a final preliminary to taking up a study of the use of fertilizers on specific crops. We shall here discuss the general principles of crop-rotation and make some illustrative applications, but more definite details will be presented in subsequent chapters in connection with the use of fertilizers with particular crops.

Crop-rotation is a systematic arrangement for growing different crops successively on the same soil. The general object is to utilize the plant-food in the soil most economically and, at the same time, maintain the soil in such condition, physical, chemical and biological, as will promote the growth of maximum crops. The particular system of rotation to be used must depend upon the kind of soil and character of farming. A fruit-grower, a dairyman, a wheat-grower, a cotton-grower, etc., would each follow different systems of rotation.

The rotation of crops as a system is in contrast with the one-crop system by which the same kind of crop is grown continuously year after year on the same soil. Under the one-crop system, soils sooner or later show decrease in crop production, which is usually due, in part, to a diminished supply of available plant-food and, in part, to deterioration of the soil in such a way as to ren-

der it unfavorable in one or more of its relations, physical, chemical, and biological.

We shall consider the subject under the following divisions:

1. Reasons underlying crop-rotation.
2. Effect on crop production.
3. General principles of crop-rotation.

CROP-ROTATION EXPERIMENTS. MINNESOTA STATION.

REASONS UNDERLYING CROP-ROTATION

The practice of growing different crops in systematic succession on the same soil was the outgrowth of observation and experience; the beneficial effects in the way of increased crop production were observed long before the reasons for the effects were understood. Some of the advantages of crop-rotation are probably not clearly understood yet. We can better comprehend the reasons

for the rotation of crops if we know what such a system can accomplish when effectively controlled; among the principal things that it may do are the following: (1) Changes location of feeding-range of plants; (2) changes the demand for individual plant-food constituents; (3) makes most advantageous use of remains of preceding crops; (4) provides economical supplies of nitrogen; (5) maintains supply of organic matter in soil; (6) keeps soil in good physical condition; (7) provides advantageous means of utilizing both farm manure and commercial plant-foods; (8) it keeps the soil advantageously occupied with crops most of the time; (9) it prevents or reduces injury caused by poisonous substances in soils; (10) it aids in controlling injuries done by insects, weeds and fungi; (11) it often saves labor; (12) it systematizes farming. We will now briefly consider each of these points.

Changes in location of feeding-range.—A properly planned rotation provides for alternation of crops whose root systems occupy different portions of the soil, as, for example, deep and shallow. The plant-food is thus taken from different portions or layers of soil, with more or less from subsoil. By this treatment the available plant-food in any one layer is less quickly reduced and, therefore, applications of fertilizers are called for in smaller amounts or less frequently. In some soils the potassium and calcium are more largely in the subsoil, while the nitrogen and phosphorus are mainly in the upper layer. To illustrate the two types, wheat crops obtain their supply of food from surface soil, while clovers go deep for more or less of their food.

Variation in demand for special forms of plant-food.—Some crops use more nitrogen than others, some more potassium, etc. The continuous growing of one crop which consumes large amounts of potassium would sooner or later tend to reduce the available supply in re-

lation to phosphorus and nitrogen; if such a crop were followed by one requiring less potassium, the latter might grow satisfactorily when the former did not. This was formerly given as the chief reason for crop-rotation. While it may be valid in some cases, it is not now regarded as of great fundamental importance.

Advantageous use of preceding crop residues.—After a crop of clover, it is better to grow wheat and then oats rather than the reverse, because the ability of oats to acquire plant-food is more vigorous than that of wheat. If oats were grown first, wheat might be at a disadvantage unless fresh supplies of plant-food were furnished the wheat. Crop residues are therefore best utilized by a judicious arrangement of crops.

Economical supply of nitrogen.—The value of nitrogen-gathering crops has already been considered (p. 351). In a four or five-year rotation system, the use of a leguminous crop will, with one application of good farm manure, maintain the soil nitrogen practically undiminished under ordinary cropping conditions. Such a system reduces to a minimum the purchase of commercial forms of nitrogen.

Maintenance of organic matter in soil.—When hoed crops or grain crops are continuously grown, the organic matter of the soil gradually becomes less, because the crop residues are insufficient to take the place of the organic matter that has undergone complete decomposition. Loss of organic matter, if not replaced, sooner or later unfavorably affects the physical, chemical and biological conditions of the soil, with consequent reduction of crop yield. The use of green-crop manures and of farm manure in a rotation provides means for maintaining an abundant supply of organic matter.

Good physical condition of soil.—Each class of crops exercises a specific action upon the mechanical condition of soils. Grass crops tend to make a soil compact; grain

1 2 3 4

ALFALFA AS A FERTILIZER IN CROP-ROTATION. WYOMING STATION.

1. Wheat from land used for rotation without leguminous crop. 2. Wheat from alfalfa land; gain per acre over 1: 718 lbs. grain and 1,500 lbs. straw. 3. Oats from land used for rotation without leguminous crop. 4. Oats from alfalfa land; gain per acre over 3: 1,291 lbs. grain and 3,500 lbs. straw.

and hoed crops tend to keep the soil structure in open condition. Proper rotation gradually alternates these conditions. The frequency and extent of compacting and loosening can be made to vary with the character of the soil. Sandy soils need crops that compact, while clay soils need more those crops that will lighten.

Advantageous use of farm and commercial plant-foods. Proper systems of crop-rotation furnish economical results when farm manure is applied to the soil once at least in a rotation of four or five years. As previously suggested, most of the additional nitrogen needed can be supplied by leguminous crops. Little commercial nitrogen will be required, the balance of crop-feeding being mainly with potassium and phosphorus compounds. When commercial plant-foods are used, they are usually applied to best advantage on the shallow-rooted crops known as so-called weak feeders.

Occupation of soil by crops.—Crop-rotation makes it possible to keep the land occupied with a crop of some kind most of the time. This is an advantage in preventing the loss of plant-food by leaching. Thus, when grass seed is put in with a grain crop, the grass crop occupies the land when the grain crop is removed. When corn follows grass, the land is kept covered by the grass until plowed for corn. Where long seasons permit, it is possible to grow in rotation more than one crop in a year.

Antidote to soil poisons injurious to crops.—Soils on which crops are grown may contain substances that are poisonous to plants (p. 128). Whatever the source of such poisons, whether excretions from plant roots or products of decomposition of soil organic matter, it is held that change of crops removes these poisons or in some way modifies conditions so that they do not injure the succeeding crop when of a different kind.

Control of injuries from insects, weeds and fungi.—

Each crop appears to be associated with certain weeds that grow with it; continuous growing of the same crop favors increase of the weeds characteristic of that crop. By changing from one crop to another very different in character, as for example, from small grains to a cultivated crop, the weeds that flourished with the previous crop are often killed easily by cultivation. In a similar manner, rotation frequently is a great aid to farmers in preventing or lessening destruction caused by insects and plant diseases. Diseases and insects that infest one crop cannot flourish when a crop of another kind takes the place of the first. Where one crop is grown continuously, the propagation of insects and disease germs carries them through from one year to another. If crops of other kinds occupy the soil three or four years, these destructive enemies disappear more or less completely.

Saving of labor.—The saving of labor by crop-rotation is shown in various ways. For example, when a grain crop is seeded to grass, the two crops are served by one operation of preparing the land. Crop-rotation means variety of crops in place of one special crop. With a variety of crops, labor is more uniformly distributed through the season instead of coming all at the same time.

Systematizing farming.—When once a system of crop-rotation is established, the management of a farm is much simplified. It is simply planning years ahead for each field of the farm.

EFFECT OF ROTATION ON CROP YIELD

Judicious use of crop-rotation invariably proves more profitable than the one-crop system. One of the best illustrations known is the experience of the Rothamstead experiment station in England, where they have continuously carried on experiments on the same field for

over 60 years. While it has been possible with the use of fertilizers to grow good root crops without rotation, grains like wheat and barley are benefited by rotation while leguminous crops ran out completely when grown continuously on the same soil. Wheat on the one-crop system gave a yield of about 12 bushels an acre, while in comparison in a 4-year rotation (turnips, barley, clover, wheat) the yield was over 28 bushels; similar differences were obtained in the case of barley grown with and without rotation.

GENERAL PRINCIPLES OF CROP-ROTATION

From the statements already made regarding the beneficial effects that may be realized by use of well-planned rotations, we can derive a few general principles, which may be regarded as embodying the essentials of a typical rotation for conditions of general farming. Under this head we will consider the following points: (1) Essentials of a rotation system, (2) conditions affecting rotation systems, (3) order of crops in rotation, and (4) examples of successful rotation systems.

Essentials of rotation system.—In planning rotations under usual conditions, four general classes of crops should be provided for, as follows:

(1) *One crop to be sold, or money crop,* usually removing considerable amounts of plant-food.

(2) *One leguminous crop* for adding nitrogen, collecting subsoil phosphorus and potassium and furnishing organic matter.

(3) *One crop for feeding farm animals,* the plant-food of which is largely restored to the soil in manure.

(4) *One cultivated or hoed crop* for destroying weeds and improving physical condition.

In illustration of these statements, we can use the

familiar three-year rotation of potatoes, wheat and mixed clover and timothy. Potatoes and wheat furnish two money crops; potatoes, the cultivated crop; wheat-straw and hay, two feeding-crops; clover, the crop for supplying nitrogen, etc.

Conditions affecting rotation systems.—Obviously, a system of rotation must, in addition to other requirements, be adapted to special conditions, which vary greatly and among which we mention the following:

(1) *Climate* quite definitely prescribes the particular kinds of crops that can be selected for a given locality.

(2) *Soil.*—Attention has already (p. 100) been called to the fact that certain crops give better results on particular types of soil.

(3) *Kind of farming.*—The crops in rotation systems will vary according to whether the farming is general or special and according to each specialty. Different details are demanded, for example, by dairying, stock-raising, grain-raising, cotton-growing, fruit-growing, etc.

(4) *Commercial conditions.*—One is limited also, in addition, to crops that can be sold readily and at profitable prices. Accessibility to market, involving transportation facilities, must also be taken into consideration.

(5) *Condition of soil* in relation to weeds, injurious insects and plant diseases must be considered.

Order of crops in rotation system.—No strict arrangement of specific crops in rotation can be prescribed, but the facts that have been presented already furnish some helpful suggestions, which we will briefly mention.

(1) Shallow-rooted and deep-rooted crops should be alternated.

(2) Crops which furnish organic matter should be alternated with those which favor its rapid decomposition.

(3) There should be in every rotation system not less

than one leguminous crop in order to increase the supply of plant-food in the soil.

(4) Crops in rotation should vary as much as possible in such respects as the amounts and kinds of plant-food requirements, character of root growth, and the time of year during which they cover the soil.

(5) In connection with the preceding statements, we may add here that whenever commercial plant-foods are used, they should be applied to the special crop that will be most benefited by them, usually the shallow-rooted, weak-feeding crop, such, for example, as wheat.

EXAMPLES OF SUCCESSFUL ROTATION SYSTEMS

We will close our discussion of crop-rotation by giving examples of well-known systems in extensive use.

(1) *Three-year rotation in potato-growing:* (1) Potatoes, (2) wheat or oats, and (3) clover and timothy.

(2) *Four-year rotation in corn-growing:* (1) Corn, (2) corn, (3) oats or wheat, (4) clover and timothy.

(3) *Five-year rotation for general farming:* (1) Corn, (2) oats, (3) wheat, (4) clover and timothy, (5) clover and timothy.

(4) *Seven or eight-year rotation where alfalfa is grown:* (1) Alfalfa for 4 years, (2) corn 2 years, (3) oats or wheat 1 or 2 years.

(5) *Three-year rotation in cotton-growing:* (1) Corn accompanied by cowpeas planted between rows or sown broadcast when last cultivated, (2) oats followed by cowpeas the same season, (3) cotton.

(6) *Five-year rotation in dairy-farming:* (1) Corn, (2) corn, (3) oats seeded with clover and timothy, (4) hay, (5) pasture.

PART IV

Practical Use of Fertilizers in the Growing of Individual Crops

CHAPTER XXVII

SOME PRELIMINARY CONSIDERATIONS ABOUT PRACTICAL USE OF FERTILIZERS

The preceding chapters have been intended to serve as an introduction to the study of the practical use of fertilizers in the growing of individual crops. We have endeavored to consider the principal facts that contribute to a more intelligent and complete understanding of the reasons for, and methods of, using fertilizers; and we have tried to keep in mind those factors that control the production of crops, especially those conditions affecting the efficiency of plants in the utilization of their food. Before entering upon the last phase of our study, the practical application of the facts and principles that have been occupying our attention, we wish to review briefly, for the purpose of additional emphasis, some of the fundamental conditions underlying the successful growing of crops, and to add some further statements upon a few points of practical importance which have not been given sufficient attention. The ground we wish to cover is suggested by the following topics:

1. Factors affecting the efficiency of fertilizers.
2. Some common mistakes about fertilizers.
3. Small and large applications of plant-food.
4. Relative amounts of plant-food constituents in fertilizers.
5. Limitations of usefulness of fertilizer formulas.
6. Plant-food formulas for crops.
7. Methods and times of applying fertilizers.

EXPERIMENTS IN CORN-GROWING WITH AND WITHOUT FERTILIZERS

Upper view: No fertilizing material added to soil; yield, 29.4 bushels. Lower view: Soil supplied with lime, with nitrogen and organic matter (in a leguminous green-manure crop), with phosphorus and potassium; yield, 64.1 bushels. ILLINOIS STATION.

FACTORS AFFECTING THE EFFICIENCY OF FERTILIZERS

In order that plants may make efficient use of plant-food and grow well, the following conditions are fundamentally essential:

(1) Good seed.

(2) Sunshine (light and warmth).

(3) Adaptation of crops to special conditions of soil and climate.

(4) Sufficient rainfall, properly distributed.

(5) Suitable physical structure of soil, making conditions favorable for the growth of plant-roots in respect to (a) mellowness and firmness, (b) receiving, distributing, holding and giving up water, (c) circulation of air, (d) absorbing and holding heat.

(6) Presence of beneficial micro-organisms in soil and conditions favorable to their growth.

(7) Absence of substances poisonous to plants, especially acid compounds.

(8) Abundance of available plant-food within reach of growing roots.

Most of these conditions are under control, and the most effective and economical means of control are, in brief, the following:

(a) Seed selection with reference to variety, vigor or vitality, purity or freedom from presence of other seeds, and freedom from disease.

(b) Adaptation of crops to soil and climate is commonly well understood for standard crops, as the result of observation and experience.

(c) Where irrigation is practicable, moisture supply is under control.

(d) The physical structure of the soil is controlled, according to special conditions, by (1) under-drainage, (p. 156), (2) thorough tillage of proper character and at suit-

able times (p. 153), (3) proper rotation of crops (pp. 498-507), (4) periodical incorporation of organic matter (pp. 348-362), (5) maintaining supply of calcium carbonate in soil (p. 379).

(e) The presence in soils of beneficial micro-organisms (nitrifying, ammonifying, nitrogen-gathering) is secured when necessary by means of inoculation through treatment with farm manure, use of soil, or special preparations, according to special circumstances (pp. 223-230). Conditions favorable to maintaining desirable organisms in soils (pp. 198-220) are provided by keeping the physical structure in good condition in the manner stated in the preceding paragraph.

Assuming that the conditions preceding are satisfactory, crops are able to make efficient use of plant-food that is within reach. Unfavorable conditions in any one respect may make a crop unable to utilize the plant-food that lies immediately at hand ready for use. Practically, all other conditions are preliminary and, in a sense subordinate, to the one final purpose of enabling the plant to obtain and use its food. When climate and the physical conditions of soil are suitable for crop growth, the primary problem of crop production is crop-feeding. Sufficient supply of available plant-food to meet crop demands is maintained most effectively as follows: (1) By the most careful saving, management and use of all excrements of farm animals, both liquid and solid, as well as of all forms of organic farm refuse (pp. 288-347); (2) by desirable rotation of crops (pp. 498-507); (3) by the use of leguminous crops or crop residues as green-manure to add nitrogen and organic matter to the soil as well as change insoluble plant-food materials into available form (pp. 348-362); (4) by maintaining in the soil a sufficient supply of calcium carbonate (pp. 379-389); (5) by the use of purchased plant-food materials in such amounts and forms as to supplement most economically the local needs

of the soil in relation to crop-feeding under the system of farm management in practice.

SOME COMMON MISTAKES ABOUT FERTILIZERS

There are among farmers many erroneous ideas in regard to plant-food and the use of fertilizers. It is not our purpose to take these up for any full treatment, but simply to call attention to a few typical cases with which the writer has been impressed in his contact with farmers. These beliefs come usually from a wrong interpretation of facts of observation and experience. The special points to be considered are the following: (1) Plant-foods and stimulants, (2) soils of excessive richness, (3) acid phosphate and "souring" of soils, (4) relation of fertilizers and tillage, (5) use of too small amounts of fertilizers, (6) mistakes about the action of some calcium compounds, (7) soil inoculation and fertilizers.

Plant-foods and stimulants.—Commercial fertilizers, whether complete or in the form of unmixed materials, are often regarded as stimulants, injuring the physical qualities of the soil as well as leading to more rapid exhaustion of plant-food. This belief is based upon the observation that in many cases where farmers have relied blindly upon the exclusive use of commercial fertilizers, they have been compelled to use increasingly larger amounts to maintain crop production, and even then have failed after a time to keep up crop yields, the soil becoming compact and more difficult to keep mellow and porous, suffering severely in times of drouth and manifesting other undesirable properties; often such soils will refuse longer to grow clover. The decreasing crop yield is often explained as being caused by exhaustion of the plant-food of the soil through overstimulation due to the use of commercial fertilizers. In most cases, the true ex-

planation is found in the failure to keep the soil well supplied with organic matter, whether owing to lack of proper rotation, or insufficient supply of farm manure. In many cases, the lack of organic matter is also accompanied by decrease of calcium carbonate, resulting in soil acidity. Under such circumstances, the application of increasing amounts of nitrogen, phosphorus and potassium compounds is worse than useless, since the crop cannot satisfactorily use the food offered and the soil condition is simply aggravated. It must be kept in mind that commercial fertilizers furnish either no organic matter or only amounts so insignificant as to be of no use in influencing the physical condition of the soil.

In support of the belief that commercial fertilizers are simply soil stimulants and not plant-food at all, it has been argued that farm manure is the only material containing real plant-food, as shown by the results of its use. It is obvious that the essential difference is in respect to organic matter, which is furnished so abundantly by farm manure and the beneficial effect of which upon soils has been frequently emphasized in preceding pages.

Commercial fertilizing materials are not mere stimulants, but contain genuine plant-food constituents which will promptly manifest their beneficial action when given a fair chance. The writer's conception of a real soil stimulant is a substance which, while furnishing no plant-food, makes insoluble plant-food constituents in the soil available; while it appears to be furnishing plant-food, as evidenced by increased growth of crops following its application, it is simply promoting the using up of real plant-food. Gypsum or land-plaster is a typical soil stimulant or, at least, was extensively so used once; when it is applied under certain conditions (p. 374) it promotes crop growth, without itself furnishing any appreciable part of the plant substance. The continuous

application of a soil stimulant sooner or later fails to produce satisfactory results, no matter how favorable general conditions for crop growth are.

Sodium nitrate is often regarded as a stimulant in the sense that its use calls for increased amounts of phosphorus and potassium (p. 67). While increase in nitrogenous plant-food usually stimulates increased vegetative activity, which calls for increased use of phosphorus and potassium, the nitrogen itself takes part in the growth and is the immediate agent of activity. Of course, prolonged use of sodium nitrate or other nitrogenous plant-food without providing any available phosphorus or potassium will sooner or later reduce the soil supply of one or both of the latter constituents to a point where the crop demands may not be adequately met. The long-continued and exclusive use of fresh farm manure may bring about a similar condition.

Soils of excessive richness.—It is common in agricultural literature to find soils, on which the growth of stems and leaves is excessive, described as very rich, or as too rich for certain crops. The statement is often made that the use of large amounts of farm manure will make a soil over rich for some crops. To many, if not most, minds, this use of the word richness, applied to soils, means too much plant-food, whereas the condition is simply one of too much nitrogen in relation to available phosphorus and potassium, or stated in another way, the soil is not rich enough in available phosphorus and potassium for the amount of available nitrogen present. Therefore, a soil that is popularly known as too rich is one that is too rich simply in nitrogen as compared with phosphorus and potassium. When fresh farm manure is applied to a soil in large amounts, the urinary nitrogen rapidly changes, first into ammonia, and then into nitrate nitrogen, while the phosphorus, contained mostly in the insoluble solid excrement, becomes available much more slowly than the

nitrogen; under these conditions, if the soil does not contain enough available phosphorus to balance the large supply of nitrogen, we get the rapid, rank growth of leaves and stems, so characteristic of heavy feeding with nitrogen. Owing to the association of nitrogen and organic matter, especially in farm manure, it is common to speak of a soil containing large amounts of well-decomposed organic matter as being rich.

Acid phosphate and "souring" of soils.—It is generally believed that the use of acid phosphate tends to make soils acid, on the ground that soluble calcium phosphate is an acid salt and also that, when carelessly made, it may contain a small amount of free sulphuric acid. It must be remembered, however, that acid phosphate and other superphosphates contain considerable amounts of gypsum (hydrated calcium sulphate) and that this tends to undergo changes in the soil which set free sulphuric acid and this in time may accumulate in sufficient amounts to make a soil acid unless there is some basic compound to neutralize it, such as calcium or magnesium carbonate. We do not know of any experimental evidence showing that pure soluble or acid calcium phosphate tends by itself to make a soil acid. The acid portion of the compound (PO_4) is sooner or later removed from the soil by growing plants.

Where acid phosphate has been used in considerable amounts the complaint is often heard that it "uses up," "burns out," "exhausts" the soil, as apparently evidenced by decreased crop yield. This is usually due to one or both of two causes: (1) To soil acidity, (2) to insufficient organic matter, conditions easily corrected, not by discontinuing the use of acid phosphate, but by applying calcium carbonate or organic matter or both. It is known that on distinctly acid soils, the amount of available phosphorus is small, while the proportion of very insoluble iron and aluminum phosphate is unusually high.

Relation of fertilizers and tillage.—Whether unconsciously or not, some farmers believe that crops, when heavily fertilized, do not require the amount of tillage, either in preparation of soil or in subsequent care, that unfertilized crops do. This is a serious error, as can be readily appreciated, when one stops to consider that the extent to which a crop utilizes plant-food depends upon the ease with which the young growing roots can extend themselves through the soil, and this depends in turn upon the mellowness of the soil, which again depends upon tillage. In general, the rule should be that the larger the amount of fertilizer applied, the more thorough should be the tillage.

Use of too small amounts of fertilizers.—The general tendency among not a few farmers is to use fertilizers, if they use them at all, in too small amounts. It is not often that farmers make any kind of a test to learn what amounts of fertilizers they can use most economically, and so they may be using amounts too small to be of any value without being aware of it. It may be safely said that it is, in general, useless to apply per acre less than 5 pounds of nitrogen, 15 pounds of phosphoric acid (6.6 phosphorus) and 10 pounds of potash (8.3 potassium); these amounts are contained in about 35 pounds of sodium nitrate, 110 pounds of acid phosphate and 20 pounds of potassium chloride.

Mistakes about the action of some calcium compounds. There are two common misconceptions in relation to the use of calcium compounds in soils. The writer is often asked about the advisability of using gypsum or land-plaster (hydrated calcium sulphate) to neutralize soil acidity. This material not only has no power to neutralize soil acidity, but, if applied to an acid soil, is likely to increase acidity. The use of commercial gypsum directly on soils is emphatically not advised; if used at all, it should be in connection with manure in stables (p. 317).

Much has been written about the injurious effect of the application of "caustic" lime to soils, especially in connection with the destruction of soil organic matter. The common explanation is that whatever change occurs is due to the direct chemical or "caustic" action of the lime itself upon the organic matter. While the caustic effect of quicklime (calcium oxide) is well known, especially during the process of slaking when high temperature develops, we must keep in mind that the quicklime is usually completely slaked before it is applied to the soil; and it is slaked lime (calcium hydroxide), not quicklime (calcium oxide) with which we have to do commonly. We must bear in mind further the following facts: (1) That one pound of slaked lime requires about 100 gallons of water to dissolve it, forming the solution known as "lime-water"; (2) that only a comparatively small amount of slaked lime is in solution in the soil even when a ton is applied; (3) that it is rapidly converted into carbonate; (4) that the "caustic" action of lime-water is very slight, as evidenced by the fact that it is often given to babies in milk in a concentration probably greater than that found in a freshly limed soil.

That the application of slaked lime to soils tends to lessen the amount of organic matter more rapidly than in case of unlimed soils is not satisfactorily explained by the direct caustic action of slaked lime. Such a result is undoubtedly due rather to the increased activity of the soil micro-organisms that decompose organic matter, the conditions of their activity being made more favorable by the presence of the dilute calcium hydroxide solution. The greater effect on decomposition of organic matter in case of slaked lime as compared with calcium carbonate is probably due to the greater solubility of the slaked lime.

Soil inoculation and fertilizers.—Owing to the exploitation of soil inoculation (p. 223) in popular magazines

by writers of imaginative rather than scientific training, much misconception has prevailed in regard to the limitations of the results of soil inoculation. Not a few have been led to believe that soil inoculation can take the place of a complete fertilizer and can furnish to the soil all the plant-food a crop needs. Soil inoculation is useful only at the present time in certain cases in getting leguminous crops well started and in no case is it associated with adding any form of plant-food to the soil except nitrogen.

SMALL AND LARGE APPLICATIONS OF PLANT-FOODS

We find that in practice farmers use fertilizers in amounts varying all the way from 100 to 3000 pounds, or even more, per acre. While the usual purpose in using fertilizers is to supplement the soil's supply of plant-food, there are two points of view in mind, (1) helping crops to start, and (2) helping them throughout their entire period of growth.

Fertilizers to start crops.—It is a well-known fact that amounts of plant-food materials as small as 100 pounds an acre often have a marked effect upon crops in their first stages of growth. The explanation most commonly accepted is that the available plant-food supply, especially of nitrate nitrogen, is at its lowest on cropped soils early in spring in temperate climates, and that the plant-food present may be insufficient to give the new crop what it needs for a quick start; therefore, to help the young crop until the soil can furnish new supplies of available plant-food, a small amount of quickly available plant-food is applied. In addition, it must be kept in mind that the roots of young plants have a very limited reach and that also they best utilize the most soluble forms of plant-food. Therefore, the application of comparatively small amounts of easily soluble plant-food

materials at this time, just where the young rootlets can quickly reach it, furnishes nutrition when most needed. The oat crop furnishes an illustration believed to be in support of the foregoing explanation. Soon after the period of germination, there is usually a space of a week or ten days when the growth is at an apparent standstill, known to farmers as the "pouting" time. Generous application of nitrate nitrogen and soluble phosphorus usually shortens or prevents this behavior, which suggests the absence of soluble plant-food within reach of the young plant rootlets. After the range of feeding-roots has been considerably extended and the various agencies in the soil have begun actively to furnish available plant-food, the soil's supply is expected to meet the crop demands during the remainder of the season.

The foregoing explanation of the markedly beneficial effects following the application of very small amounts of available plant-foods is rejected by some on the ground that the amount of nutritive material thus furnished is altogether too small to have any effect in the direct nutrition of a crop. Two other explanations are offered. According to one, the fertilizer applied simply renders harmless the poisonous substances left in the soil by the preceding crop and, after the destruction of these plant toxins or poisons, the young plants of a new crop have a better chance to grow. While this may be a partial explanation in some cases, it is not yet generally accepted as proved; it is, however, an interesting, suggestive and promising line of investigation. Thus, in laboratory experiments, the use of nitrate prevents the injurious effects of certain soil toxins on plants; the application of phosphates neutralizes certain other soil toxins, while potassium compounds overcome the effects of still others. The second explanation offered by those who deny that small applications of plant-foods have value as direct plant-nutrients is that the materials applied effect physi-

cal and chemical changes in the soil which result in making conditions favorable other than those relating to direct nutrition. Whatever may be the real explanation, the fact of the effect of fertilizers in small amounts upon young plants in early spring is familiar in farm practice.

Fertilizers to help crops continuously.—In some cases, farmers apply as much available plant-foods as a large crop will use, or even in considerable excess of this, in order to make sure of enough, practically ignoring the supply contained in the soil. For example, the writer knows of instances where potato-growers apply per acre in available forms 60 pounds of nitrogen, 120 pounds of phosphoric acid (53 phosphorus) and 150 of potash (125 potassium), when the crop uses only about 50 pounds of nitrogen, 20 of phosphoric acid (9 phosphorus) and 70 of potash (58 potassium). Other potato-growers apply such amounts of fertilizer as they think will supplement the supply furnished by the soil during the growing season, under the conditions of their soil, crop-rotation, etc., basing their judgment upon previous observation and experience. In the case of market-garden and greenhouse crops, it is the custom practically to ignore the soil's plant-food supply and apply commercial plant-foods in amounts large enough to insure not only large crops, but often also to hasten the maturity in order to get the advantage of high prices early in the season. This system, however, is not profitable in the case of ordinary farm crops.

RELATIVE AMOUNTS OF PLANT-FOOD CONSTITUENTS IN FERTILIZERS

In commercial fertilizers, we find the relative proportions of nitrogen, phosphorus and potassium varying, different formulas being prescribed for different crops. It may be a matter of interest to know what have been

some of the methods of procedure in determining or trying to determine the proportions of nitrogen, phosphorus and potassium in making fertilizers for different crops and what the real significance of such variations is. We have already (p. 408) discussed the attempt to measure the plant-food needs of a soil by means of chemical analysis and have seen that, while it will furnish helpful suggestions, it has not been found a satisfactory or practical basis when used alone without reference to various other conditions. Another proposition, which is still influential, was to make the application of fertilizers correspond to the chemical composition of the plant (p. 422). Much emphasis has been placed by some upon the two phrases, "feeding the soil" and "feeding the crop," meaning the use of fertilizers on the basis of soil analysis and of plant analysis. Some fertilizer manufacturers claim that their formulas are based upon feeding the plant and not the soil. A knowledge of the amounts of nitrogen, phosphorus and potassium used by different crops is exceedingly desirable and useful and necessary in studying the plant-food needs of crops, but, for reasons already pointed out, this knowledge is insufficient to serve by itself as a basis for enabling us to determine the relative amounts of different plant-food constituents to use.

The present use of plant-food materials, in relation to the amounts applied, is based, (1) in part, upon the amounts of plant-food removed by crops, (2) in part, upon the character of soil, and, (3) in larger measure, upon laboratory investigations and actual field tests first carried out by our agricultural experiment stations and then applied in successful farm practice by progressive farmers.

If we compare the proportions of nitrogen, phosphorus and potassium in most fertilizers with the proportions of these constituents as found in crops to which the ferti-

lizers are applied, we notice that the nitrogen is usually much less, the phosphorus very much more, than the proportions called for by the composition of the crops. For example, phosphorus is used by crops in smaller amounts than either nitrogen or potassium and yet, in nearly all fertilizer formulas, we find that phosphorus is generally in considerable excess of the other two constituents. In departing from the proportions of constituents found in plants, certain facts are taken into consideration, among which we mention the following: (1) A smaller amount of nitrogen is applied in fertilizers than the crop uses, on the assumption that the soil will furnish considerable, especially as the growing season advances and conditions become favorable to decomposition and nitrification processes. This assumption, to be safe, should be based upon actual knowledge as to previous soil behavior and treatment. The use of farm manure and leguminous green-manure, for example, justifies the assumption. Generally speaking, clay soils contain more nitrogen than sandy soils, while muck or peaty soils, though rich in nitrogen, do not furnish any appreciable amount of quickly available nitrogen until they have been tilled and, in many cases, limed. Soils lacking in organic matter usually need nitrogen. (2) The amount of phosphorus in a fertilizer is usually increased much above the proportion called for by plants, especially in the case of cereals, for the reason that most soils contain phosphorus in relatively small amounts and much of it generally in forms not quickly available except as the result of treatment with organic matter, lime, etc. The fact that a soluble phosphate reverts in most soils before it is used by crops probably has had something to do with this use of relatively large amounts of phosphorus. (3) The proportions of potassium are made to vary with the character of the crop as well as with the character of the soil. On most clay

soils, when kept well supplied with calcium carbonate and organic matter, or when treated generously with sodium nitrate, little potassium need be used in fertilizers. Larger amounts are called for by leafy crops, root crops and some others than by cereals. Light, sandy soils are often deficient in available potassium, while muck soils are generally found to respond most favorably to generous applications.

From the preceding discussion, it can be readily appreciated that the making of a useful fertilizer formula is a matter of no small complexity and, in no case, can a mixture be made that will be found equally useful on different farms even for the same crop.

LIMITATIONS OF USEFULNESS OF FERTILIZER FORMULAS

When we come to specifying definite formulas or definite amounts of plant-food materials for particular crops, we want to make it clearly understood now, if we have not succeeded in doing so before (p. 406), that no specific formulas or amounts of plant-foods can be prescribed for any crop under all conditions nor for every crop on a given soil. The question of quantities and proportions of plant-foods to be used must always, in the very nature of the case, remain more or less a matter of individual experience and observation. Moreover, it must be remembered that one's practice cannot remain continuously the same. The soil of each field is undergoing constant change in the extent and character of its needs. For example, the fact that the application of acid phosphate gives large crop yields for one year does not mean that this treatment will continue to give the same results indefinitely. Sooner or later, and generally sooner, crop yields will drop, unless attention is given to the supply of nitrogen or potassium or calcium, or organic matter, or all of these.

The chief use of a fertilizer formula is as a suggestion or starting-point. Beginning with a suggested formula, the progressive farmer will constantly study results and let the experience of one year suggest to him his plan for the year following. It is unwise to be permanently attached to any one combination of plant-foods, unless one has proved by long-continued experiment that it gives the best possible results under the conditions prevailing on the individual farm or field for particular crops. In making variations in the amounts and forms of plant-foods to be used, home-mixing becomes essential. The disadvantage of being wedded to a single mixture of plant-foods is well illustrated in the case of a certain community engaged in raising market-garden crops. The farmers had all come to use one kind of plant-food mixture, until carefully conducted experiments proved that they were using twice as much potassium as they needed and in many cases were applying the mixture in amounts twice as large as was consistent with the best profit.

Every fertilizer formula, from whatever source it emanates, should be regarded by the individual farmer as an experiment or, perhaps, rather as the beginning of a series of experiments, which will sooner or later lead him to make the most economical use of plant-food materials that his conditions will permit.

The ideal system, all things considered, is that commonly followed by the most progressive German farmers, who do not apply plant-foods by formulas of mixtures but as separate materials. In their system of farming, they apply nitrogen, phosphorus and potassium separately, usually in different seasons, in accordance with the results of their observation and experience. The successful application of such a system demands a close study, not only of crops, but of the science of plant-feeding; it has the advantage of enabling the farmer to

make the most economical use of all plant-food materials in crop-growing.

PLANT-FOOD FORMULAS FOR DIFFERENT CROPS

The number of fertilizer mixtures containing nitrogen, phosphorus and potassium compounds, offered for sale to the farmers of the United States, is very large, aggregating many thousands. While these mixtures differ much in general composition, it is found that a comparatively few formulas include a large percentage. It is probably true that the real interests of farmers would be better served, if there were not more than six different mixtures for general farm use, with a few special modifications to meet particular conditions. In harmony with this statement, the writer suggests the following formulas, which, modified to meet special conditions, will be made the basis of practice in the subsequent chapters of this book.

TABLE 53—PERCENTAGE COMPOSITION OF PLANT-FOOD FORMULAS FOR GENERAL USE

Kind of crops	Per cent. of nitrogen	Per cent. of available phosphoric acid (P_2O_5)	Per cent. of potash (K_2O)
LEGUMINOUS	1	8 (3.5 P)	10 (8.3 K)
CEREAL	3	8 (3.5 P)	5 (4.2 K)
GARDEN	4	8 (3.5 P)	10 (8.3 K)
GRASS	3	6 (2.5 P)	9 (7.5 K)
ORCHARD	2	5 (2.2 P)	10 (8.3 K)
ROOT	3	8 (3.5 P)	7 (5.8 K)

P, phosphorus. K, potassium.

The special modifications of these to meet special conditions and the amounts to use will be taken up in connection with the discussion of individual crops. Whatever criticism may be made of the proposition of using only a few, instead of many hundred, plant-food formulas, it is safe to say that these few, especially when used in connection with the home-mixing of fertilizers (p. 476), can be

used in agricultural practice with a degree of success in no way inferior to that met in using the hundreds or thousands of commercial mixtures.

In studying the plant-food mixtures given in the following pages, it will be noticed that the commercial plant-food materials are comparatively few in number and that some familiar forms are absent altogether. The selection is based largely on the present market conditions, other things being equal. For example, dissolved bone-black, genuine dissolved bone, real guanos, unleached wood-ashes, etc., are obtainable only in comparatively small amounts and at relatively high cost of plant-food constituents. Dried blood and fish-scrap are obtainable, if one can afford to pay nearly 25 cents a pound for nitrogen, when nitrate and ammonia nitrogen and organic nitrogen in tankage can be purchased for about 15 cents. Calcium cyanamid has not been included, because it is a new material which has not yet been handled by farmers, but which experience may find to meet all conditions where ammonium sulphate is ordinarily used. There is no need to include desirable materials which may be obtainable in the future but are not at present, such as calcium nitrate (lime nitrate). Cottonseed-meal has not been included except in mixtures for southern crops, where it is good economy to employ this material. In order to furnish plant-food constituents at economical prices, cottonseed-meal needs to retail for not more than $25 a ton.

In regard to the use to be made by farmers of the suggestions for plant-food mixtures contained in the subsequent pages, it may be said that where farmers are now using methods of plant-feeding which are giving good financial returns, it is unwise to make any radical change without first making some careful experiments on a limited scale.

METHODS AND TIMES OF APPLYING FERTILIZERS

While we shall consider this subject in more detail in connection with individual crops in succeeding chapters, it is desirable to present here some of the main points of general importance.

The efficiency of the plant-food in a fertilizer is lost for the season's growing crop in so far as it does not come within the feeding range of the plant roots. That method of application is best in each case which distributes the plant-food materials most thoroughly and uniformly throughout the portion of soil with which the feeding-roots of the crop come into contact. The different phases of the subject to be noticed are the following: (1) Special machinery, (2) different methods of applying fertilizers, (3) precautions in applying concentrated fertilizers, (4) application of soluble materials, (5) distribution of insoluble fertilizers, (6) time of application.

Special machinery for distributing fertilizers.—The importance of distributing fertilizers in the most efficient manner has been fully appreciated by implement manufacturers, so that not only are all desirable forms of drills and planters provided with special attachments for this purpose, but several kinds of machines have been devised to distribute fertilizers either in the rows, beside the rows, or broadcast uniformly over the entire surface, while some forms are adjustable to make use of all three methods. As previously stated (p. 344), wagons are made for the distribution of farm manure some of which are provided also with arrangements for distributing fertilizers and lime. For broadcast distribution, an ordinary grain-drill answers well.

Different methods of applying fertilizers.—For crops whose root systems extend sideways in every direction and occupy pretty completely a horizontal layer of soil,

broadcasting, followed by harrowing before planting, is preferable. This applies, for example, particularly to fertilizers used for cereal crops, orchards, grasses, and leguminous crops (especially when grown for green-crop manure), forage, meadow and pastures. In the case of crops grown in hills and rows, whose root systems extend downward rather than horizontally, distribution in or near the rows is usually preferred, as for potatoes, roots, many garden crops, etc. When early rapid growth is desired part of the fertilizer is usually put in the hill

FERTILIZER AND LIME DISTRIBUTER

or drill with the seed and the rest applied later as a top-dressing. In the South, fertilizers are often applied alongside the rows in case of the corn crop after the plants have started well, but it is believed that elsewhere better crops are obtained by applying broadcast and harrowing in before planting. Special crops call for special methods of distribution, and successful growers differ from one another in the methods employed. Such special methods will be considered in connection with the different crops.

Each method of distributing fertilizers has some special advantages, which we will briefly notice. Drilling

saves labor and places the plant-food just where the rootlets of the young plant can reach it in the early stages of growth, when they most need it. Where the root system is limited and is confined to rows or hills some distance apart, drilling may use less plant-food than broadcasting even in case of an equally good crop. On the other hand, the tendency in drilling in fertilizers with a crop like corn is to use too little fertilizer, with the result that early growth is most promising but that in some cases not enough available plant-food is at hand to produce a sufficiently heavy yield of ears. The method of broadcasting a fertilizer insures a distribution through all portions of the layer of soil where crop roots are to grow during the season. When a fertilizer is used in large amounts so that considerable portions remain in the soil for the crop following, broadcast application is preferable. Extensive range of root is promoted by broadcasting, which is of value in enabling a crop to resist drouth.

When a farmer is using a system of application that gives satisfaction under his conditions, it is usually advisable to adhere to it and not change it for some other method until he has had a chance to test the new method experimentally in a small way and proved to his satisfaction whether or not it is likely to be more profitable.

Precautions in applying concentrated fertilizers.—A few words should be devoted to calling attention to certain dangers that may result from the careless use of high-grade or concentrated fertilizers, those that are largely made up of mineral or inorganic compounds, such as sodium nitrate, ammonium sulphate, acid phosphate, potassium chloride and sulphate, etc. These compounds in concentrated solution have the power of injuring plant tissue with which they come in contact, as we have previously explained (p. 167), producing the effect of burning. When a concentrated or high-grade fertilizer

or any plant-food material likely to burn vegetable tissue is applied, it is essential that it be kept from coming into direct contact in the soil with the seed. If, for example, a small lump of such a fertilizer should be left near seed in the soil, a strong solution of the fertilizer is soon formed and this, reaching the seed, is likely to injure it and prevent germination. In a similar way, if a young rootlet pushes into such a concentrated solution, injury follows. It is obvious that the proper way to avoid such trouble is to see that the fertilizer is in a finely divided condition, that it is uniformly distributed through the soil and that it is not applied in so large amounts as to make it difficult to meet these conditions.

A good way of handling concentrated fertilizers before application is to *dilute them by mixing thoroughly equal parts of the fertilizer and some inert substance* like fine, dry muck, or peat, sand, sifted coal ashes, fine, dry earth, etc. Such a mixture can be distributed more uniformly and with much less risk of injuring seeds or roots. This method of dilution is especially desirable when one wishes to make only small applications. For example, it would be a very difficult matter to distribute uniformly 75 pounds of sodium nitrate in dry form over an acre. Dilute it by thorough mixing with 200 or 300 pounds of fine, dry inert material, and its uniform distribution is no longer difficult.

In the matter of *top-dressing* partly grown crops with concentrated mixed fertilizers or with sodium nitrate, it is highly desirable that the concentrated materials be diluted with inert material. It is also essential that these surface applications be made not too near the growing plant and under no circumstances touching any portion of the plant. Those who have not had experience in the handling of these powerful compounds have often scattered the material over the ground near the plant, after which a heavy shower has come, dissolving the plant-

food material suddenly and spattering the concentrated solution over the plant, causing serious burning wherever plant tissue is touched and usually causing the death of the plant. It is always desirable if possible to work a top-dressing of such strong materials lightly into the soil; this will prevent the possibility of the destructive effects caused by a heavy rain. Generally speaking, it is safer to make two or three light top-dressings than one heavy application. Regarding sodium nitrate, it is generally not desirable to apply it alone as a top-dressing in amounts exceeding 100 pounds an acre at one time on most crops.

Distribution of soluble fertilizers.—Materials which are readily soluble can be distributed over the surface and lightly worked in. When the first rainfall comes, they are distributed throughout the soil completely and uniformly.

Distribution of insoluble fertilizers.—Materials that are largely insoluble are preferably well mixed through and beneath the soil. Thus, dried blood, bone-meal, tankage, fish-scrap and other organic materials of similar character are best placed at a sufficient depth in the soil to promote to best advantage the processes of decomposition and nitrification. However, the mistake should not be made of working such materials into the soil too deeply, because the decomposition may be too slow or the nitrate nitrogen, when formed, may be leached and carried beyond the reach of the roots.

Time of application.—Plant-food materials which dissolve easily and diffuse through the soil readily, and which are not reasonably well retained by the soil, are best applied only when the crop is ready to utilize them. If put on too long before the crop growth is well started, there is danger, especially on light, open soils, of their being carried more or less beyond the range of the crop roots. Nitrate nitrogen, in case of light soils, is to be

treated with special care in this respect. Ammonia is liable to a similar loss, as soon as it is converted into nitrate. Sodium nitrate is especially useful for early spring applications in case of crops that need an early, prompt start. Care should be taken not to apply sodium nitrate too late in the season in case of most crops, since the maturing of the crop will be retarded and there will be an excessive growth of stems and leaves.

Fertilizers which do not dissolve readily are preferably applied early in the season and worked into the soil so that they can undergo decomposition. To this class belong farm manure, bone-meal, dried blood, fish-scrap, tankage, cottonseed-meal, basic-slag phosphate. It is important that the nitrogen-containing materials be controlled so that they shall exercise their maximum effect before the maturing season of the crop arrives; otherwise, the season of growth may be prolonged so late into the fall as to result in injury to the crop either in yield or quality or both. In case of trees, hardiness is decreased and liability to injury by severe cold is greater.

CHAPTER XXVIII

LEGUMINOUS CROPS

Plants known in botany as belonging to the family, *Leguminosae,* commonly called the bean or pulse family, are numerous in kind and widely distributed. Those of agricultural interest are the well-known clovers, beans and peas. For several reasons, these plants are of the highest value and possess some important characteristics which distinguish them from all other crops.

GENERAL CHARACTERISTICS

The more important points of general interest relating to leguminous crops will be considered under the following divisions: (1) Relation to nitrogen, (2) relation to subsoil, (3) different uses, (4) adaptation, (5) agricultural varieties.

Relation to nitrogen.—These plants possess the peculiar power of being able to make use of atmospheric nitrogen and thus adding to the soil's supply of this plant-food available for crops. The manner in which this is done we have already considered in detail (pp. 214-223). By the adoption of some leguminous crop as part of a rotation, it is easily possible to reduce greatly the amount of costly plant-food nitrogen that one needs to purchase. However, in order to utilize this important power of leguminous crops, it is essential that the soil be provided with the proper nodule-forming organisms (pp. 223-228).

Relation to subsoil.—Many of the leguminous crops are deep-rooted and serve the important purpose of going down into the subsoil and collecting phosphorus and potassium compounds, which are carried into the upper portions of the plant and then by their decomposition given to the upper layers of the soil (p. 351).

Different uses.—Leguminous crops are devoted to a greater variety of efficient uses in agriculture than any others: (1) They are the most valuable green-crop manures known; (2) they are among the most useful forage crops; (3) many of them furnish hay of the highest nutrition; and (4) some of them are useful as pasturage and in lawns.

Adaptation.—Some varieties can be grown under quite a wide range of soil and climatic conditions, while others are much more limited. New varieties or strains are being pro-

A CROP OF ALFALFA AT THE NEW YORK (GENEVA) STATION

duced, thus increasing their adaptability. In the northern portion of the United States, the varieties most commonly grown are red, mammoth, alsike and white clovers, field peas, alfalfa and common vetch; in regions having a mild to warm climate, cowpeas and crimson clover are extensively grown; in many parts of the West, those most grown are alfalfa, clovers, cowpeas and soy-beans.

Agricultural varieties.—The number of leguminous

plants in actual use is quite large, though in many cases only in a limited way; the varieties best known and most extensively used are the following: Clovers (red, mammoth red, alsike, crimson, white), alfalfa, field-peas, cowpeas, soybeans, velvet-beans, peanuts and vetch. These crops will be treated in this chapter with the exception of garden and field-beans and peas, which will be considered under Garden Crops (pp. 614-637) and peanuts, which are placed under Special Crops (p. 695).

SOIL CONDITIONS

Under this head, we will consider: (1) Calcium compounds, (2) organic matter, (3) kinds of soils, (4) preparation.

Calcium compounds.—Leguminous crops are sensitive to the presence of acid compounds (p. 221) and do not thrive on soils that are appreciably acid. Therefore, in growing these crops, the soil should be well supplied with calcium (lime) carbonate (pp. 379-389), applied with the crop or preferably the season previous to growing the leguminous crop. These crops are also relatively large consumers of calcium as plant-food.

Organic matter.—A generous supply of decomposing organic matter is also a requisite for the most abundant yield (p. 117).

Kinds of soil.—The kinds of soil on which leguminous crops grow best vary widely. Some thrive only on one kind of soil, while others grow well on different types. In general, they require well-drained soils, but mammoth-red, alsike and white clovers grow well on lands that are too moist for other clovers. Deep-rooted crops, like red and mammoth red clovers, alfalfa, sweet clover, cowpeas, soybeans, do best only when the subsoil is free from hardpan and fairly open. In connection with each crop, we will consider more in detail the matter of soil adaptation.

Preparation of soil.—In general, much care is required in preparing the soil. For the small-seeded crops, the soil should be in fine tilth and it is, therefore, a good plan, when practicable, to let them follow a hoed crop; this also has the advantage of lessening the growth of weeds, which often become a serious trouble in such newly seeded crops as alfalfa and soy-beans.

TABULATED DATA ABOUT LEGUMINOUS CROPS

In the following tabulated summary, we give various data as a convenience for quick reference. More detailed specifications are given when needed in connection with a discussion of each special crop.

While some of the plants are perennial, they run out sooner or later when left undisturbed as in meadow or pasture. The length of time the plants persist depends upon the character of the soil, frequency of cutting crop, amount and kind of fertilizers applied, etc.

The amount of seed used varies greatly; less is used when sown in rows than when broadcasted or when sown with some other crop. Generally, larger amounts of seed are used for green-crop manures than for forage or hay and less when the crop is grown for seed. More seed is needed on soils in poor tilth or lacking in available plant-food, than on fertile soils.

In respect to depth of planting, it should be remembered, in general, that small seeds need only slight covering, while larger seeds are usually planted deeper.

The time of planting will often be governed by the special purpose one has in raising the crop, whether as green-crop manure, green forage, seed, hay, etc.

TABLE 54—DATA RELATING TO LEGUMINOUS CROPS

Variety	Soil	Root system	Duration	Amount of seed per acre: Green manure	Amount of seed per acre: Forage, etc.	Usual season of planting	Depth of planting
			Years				
Clover, red	Well-drained clay to light	Deep	2-3	12-15 lbs.	8-12 lbs.	Early spring	
" mammoth red	Moist clays and loams	Deep	3-4	15-20 "	12-15 "	Early spring	
" alsike	Moist clays and loams	Not deep	3-5	12-15 "	8-15 "	Early spring	
" crimson	Light	Not deep	1	15-20 "	12-15 "	June-October	
" white	Moist clays and loams	Not deep	4-5	12-15 "	10-12 "	Early spring	
" sweet	Clay to light	Deep	2	2-4 pks.	10-12 "	March-Septer	
Alfalfa	Well-drained clay to light	Very deep	4-10	25-35 lbs.	20-25 "	Early spring	
Field-pea	Moist clays and loams	Not deep	1	2-3 bu.	2-3 bu.	Early spring	
Cowpea	Generally on soils not too wet	Deep	1	1½-2 "	1-1½ "	May-June	
Soy-bean	Clays, loams, etc.	Deep	1	1-1½ "	2-3 pks.	May-June	
Velvet-bean	Light, sandy	Deep	1	1-4 pks.	1-4 "	Spring	
Vetch	Clays, loams, etc.	Not deep	1	1-1½ bu.	1-1½ bu.	May-August	

SUGGESTIONS ON USE OF FERTILIZERS

Leguminous crops require in soils abundant supplies of phosphorus, potassium and calcium compounds as a condition for the exercise of their power to utilize atmospheric nitrogen to the fullest extent. It is commonly stated that no plant-food nitrogen should be furnished, because, when available nitrogen is at hand in the soil, these plants will utilize this in preference to atmospheric nitrogen. While this is true with reference to the main period of growth, it will usually be found desirable on most soils, and always on poor soils, to furnish some available nitrogen, such as nitrate, in order to give the young plants a prompt and vigorous start. Application of nitrogen is particularly essential on soils that are not provided with the proper nodule-forming organisms, but every effort should be made to insure the presence of these bacteria (p. 223) if one expects to raise a leguminous crop to best advantage in every way. Whatever the special purpose for which the crop is grown, some application will generally be found useful at the start and should be applied, preferably, broadcast and harrowed in before sowing seed. On clay soils, well provided with calcium carbonate and organic matter, minimum amounts of potassium need to be furnished, while on sandy soils both potassium and phosphorus can commonly be added to advantage.

Lower ends of alfalfa roots, 7½ feet from the surface, showing nodules. COLORADO STATION.

On soils deficient in organic matter, farm manure at the rate of 8 to 12 tons an acre should be used, preferably with

the crop preceding in order to avoid weeds in the leguminous crop; for direct application, this trouble can be avoided by using farm manure that has been sufficiently decomposed to destroy weed seeds (p. 337). To furnish gradually available phosphorus, there may be applied along with the farm manure 800 to 1,000 pounds of finely ground rock-phosphate ("floats").

On soils well provided with organic matter, calcium carbonate and the suitable nodule-forming organisms, the following mixture is suggested:

Plant-food mixture, 1.—*For use in starting young crop.*

Sodium nitrate........	400 lbs.	(60 lbs. nitrogen)
Acid phosphate.......	1100 "	(150 " available phosphoric acid or 66 lbs. P)
Potassium chloride....	300 "	(150 " potash, or 125 lbs. K)
Drier (p. 480)........	200 "	

As limits within which to work, an application of 300 to 600 pounds an acre is suggested, more exact amounts being determined in individual cases either by previous experience or by special experiment. Such a mixture contains about 3 per cent. of nitrogen, 7.5 of available phosphoric acid (3.3 P) and 7.5 of potash (6.2 K). An application of 300 to 600 pounds per acre contains the following approximate amounts of plant-food:

Nitrogen	10 to 20 lbs.	
Available phosphoric acid......	25 to 50 "	(10 to 20 lbs. P)
Potash	25 to 50 "	(20 to 40 " K)

Subsequent treatment with fertilizers depends upon the individual crops and the purposes for which they are grown. The following mixture can be used at the time of seeding along with a moderate application of farm manure or when farm manure has been used in generous amounts on the preceding crop; the mixture can also be used as a top-dressing on meadows and pastures, in which the leguminous plants are to be encouraged:

Plant-food mixture No. 2.—*For use with farm manure or as later top-dressing.*

Sodium nitrate	250 lbs.	(40 lbs. nitrogen)
Acid phosphate	1150 "	(160 " available phosphoric acid, or 70 lbs. P)
Potassium chloride	400 "	(200 " potash, or 165 lbs. K)
Drier (p. 480)	200 "	

The suggested application is 200 to 400 pounds an acre. This mixture contains about 2 per cent. of nitrogen, 8 of available phosphoric acid (3.5 P) and 10 of potash (8.3 K). An application of 200 to 400 pounds an acre contains approximately the following amounts of plant-food:

Nitrogen.	4 to 8 lbs.	
Available phosphoric acid . . .	16 to 32 "	(7 to 14 lbs. P)
Potash	20 to 40 "	(16 to 32 " K)

MANAGEMENT OF LEGUMINOUS CROPS

The general methods of treatment in relation to preparation of soil, fertilization, etc., are much the same, whether leguminous crops are used as green forage or hay, or as green-crop manure (pp. 348-362). Some special considerations are involved in the growing of beans (p. 623), peas (p. 624) and peanuts (p. 709), and these crops are, therefore, considered in subsequent chapters.

Alfalfa roots, 9 months old; 9 ft. 5 in. long. COLORADO STATION.

Red clover, as a green-crop manure, is probably the most widely grown of any leguminous crop. Even the stubble and roots alone are often effective when plowed under. About one-third of the entire plant-food value is contained in the roots, while 35 to 40 per cent. of the nitrogen is found in the roots and stubble.

While adapted to a great variety of soils, red clover thrives best on well-drained, moderately heavy loams, somewhat

moist but not wet, well supplied with organic matter and calcium carbonate. Even on light soils, it gives large yields when water and plant-food are abundant, but runs out sooner than on heavier soils.

Red clover is most commonly seeded on winter wheat or rye in spring, as soon as danger of heavy frosts is past and while the ground is moist. When put in as green-crop manure, 12 to 15 pounds of seed can be used, the larger amount on poor soils.

Red clover is not generally grown simply as a green-crop manure, but is allowed to grow two years, being cut for hay or seed, and the aftermath plowed under. Clover sod is recognized as an excellent preparation for corn, potatoes, oats, etc. The beneficial effects of plowed clover sod usually last for more than one season. The roots of the red clover are widely distributed through the soil in every direction and they undergo decomposition very readily.

Red clover is a vigorous nitrogen-gatherer; an entire crop, including tops and roots, often contains per acre 100 pounds each of nitrogen and potash (83 lbs. K) and 40 to 50 pounds of phosphoric acid (18 to 22 lbs. P). Even winter-killed clover may contain 50 to 80 pounds of nitrogen and other plant-food enough to make it useful for the following crop.

When grown only as a green-crop manure, without any other crop, the application of fertilizers should be as indicated above (pp. 541-543). When grown with winter wheat or rye, these crops should be well supplied with plant-food and, after they are harvested, a light top-dressing of fine stable manure may be used, or 200 to 400 pounds of **Mixture No. 2** (p. 543).

Red clover for meadows, pastures, etc. (pp. 557-573).—When grown for seed or for use as green forage, hay or pasturage, the management of this and other clover crops with reference to feeding at the start is essentially the same as when grown for the purpose of a green-crop manure. In connection with permanent pastures, red clover in com-

mon with other leguminous plants persists longer when treated with minimum amounts of nitrogen and liberal amounts of phosphorus and potassium, while the vigor of grasses is promoted by liberal feeding with nitrogen to such an extent that they run out the clovers.

Mammoth red clover, known also as perennial, pea-vine and sapling clover, closely resembles red clover but is coarser in growth and requires two or three weeks longer to reach maturity. It can be grown on wet lands better than the common red. It is a vigorous grower and a good collector of plant-food in the subsoil. The yield is generally larger than with red clover and the growth does not run out as quickly. The general cultural treatment is essentially the same with both crops. It is well to use 15 to 20 pounds of seed per acre.

Alsike clover, known also as Swedish clover, is, on account of its creeping habit, best seeded with other crops of erect growth, as for example, with red or mammoth red clover. Alsike is well adapted to cool, moist clays and loams which are too wet for other clovers. It may be started during the summer or early fall and turned under in spring for green-crop manure, using 12 to 15 pounds of seed. Its root system is not deep and, to insure a good catch, the soil must be carefully prepared. An application of 200 to 400 pounds an acre of **Mixture No. 1** (p. 542) may be used before sowing, being well worked into the upper layer of soil. When used for forage or hay, it is seldom grown alone, and often remains three to five years.

White clover is not often used except incidentally as a green-crop manure. Its common use is in pasturage in connection with other clovers and with grasses (pp. 566-7). It grows well on lands of inferior character where red clover fails; it is also less sensitive to drouth and cold. It is adapted to a wide range of soils, but does best on moist land. Its treatment with fertilizers is the same as for red clover.

Sweet clover, known also as white melilot or melilotus, large white clover and Bokhara clover, is a leguminous plant though not a real clover. It is a familiar, hardy, roadside biennial weed, widely distributed. It grows readily on moist soils, and especially well on soils rich in calcium carbonate. Its roots are large and penetrate deep, while its tops have an abundant growth. It generally grows without application of fertilizers. On very poor soils it may be used as a preliminary crop for alfalfa or some other leguminous crop. For green-crop purposes, it is regarded as quite equal to red clover. Its action as a green manure is said to be most effective when plowed in during the second season of growth just before blossoming. The high value of this plant as a green-crop manure has not begun to be fully appreciated, especially in the northern states. The fact that animals are not usually fond of it as green forage or hay probably accounts for the lack of appreciation of its value as a green-manure crop.

Crimson clover, known also as Italian clover and German clover, is exceedingly valuable as a green-crop manure in the states along the Atlantic from New Jersey southward to Georgia. It has been grown in other states, but, owing to its sensitiveness to freezing and consequent winter-killing, it is not extensively grown north of the middle Atlantic States. It is an annual plant, flourishing in the cool weather of late fall and early spring, blossoming in April or May, when it is in best condition to be plowed under. It is not suited to spring seeding and is usually sown from July 15 to September in eastern central states and as late as October farther south. It has the advantage of growing on soils too light for other clovers and also of growing at the time of year when the cowpea does not thrive. It is excellent as a cover-crop to be used between regular crops without interfering with rotation. It is therefore suitable when seeded in corn, orchards, berry lots, etc., after regular cultivation is finished, and also after harvesting such crops as tomatoes,

early potatoes, etc. Even when the crop is winter-killed, it will be found useful as a green-manure, if it has made a six-inch growth; the organic matter in such a crop is equal to that in 4 or 5 tons of manure. The nitrogen in a full crop of crimson clover ranges from 50 to over 200 pounds an acre, while the fall growth alone may contain as much as 100 pounds. The root system is comparatively unimportant, making up only 10 per cent. of the whole crop. In improving poor lands in the middle Atlantic section, excellent success has been attained by combining crimson clover as a winter crop with cowpeas as a summer crop.

While crimson clover is adapted to light, sandy soils, it needs to be well supplied with phosphorus and potassium compounds. On land known to be lacking in plant-food it will be well to use 200 to 400 pounds or more per acre of **Mixture No. 1** (p. 542), in order to insure the crop a good start.

Crimson clover. Eighteen inoculated plants on right. Eighteen non-inoculated plants on left. ALABAMA STATION.

Alfalfa or Lucern is grown chiefly for forage and hay and only incidentally as a green-crop manure. On account of the difficulty and expense of seeding and its slow, early growth, it is not adapted to be grown solely as a green-crop manure. It does not reach its greatest growth until the second or third year after seeding. When well started once, the crop will continue growing for four to ten years or more without reseeding, the length of time depending on the soil, supply of plant-food, freedom from weeds and grass, and the frequency of cutting.

Alfalfa grows well on practically all good well-drained

soils; it does best on a rich, sandy loam with deep, open subsoil. It dies out in a year or two on cold, heavy clays and wet soils. Alfalfa is peculiarly adapted to dry regions, since its roots go down several feet into the soil after water as do those of few other agricultural plants, cases being on record of roots 30 feet long. For this reason, alfalfa is liable to injure the roots of trees if grown permanently in

Effect of inoculation on growth of alfalfa. Growth on equal areas of soil. NEW YORK STATE (GENEVA) STATION.

Soil intended for alfalfa must be deeply plowed and put into as fine tilth as possible and practically free from weed-seeds and grasses. In the North and East it is commonly sown in spring as soon as danger from heavy frost is past. It is best sown by itself without cover crop. When sown broadcast, it requires 25 to 35 pounds of seed; when drilled, 20 to 25 pounds. In the South it is customary to seed alfalfa

after some hoed crop in the fall in order to get the start of spring weeds. The seeds are generally harrowed in and the ground lightly rolled.

Alfalfa plants are extremely sensitive to soil acidity. Unless the soil has been recently treated, it is generally desirable to lime the soil at the time of, or preferably the year before, putting in alfalfa. A generous application of farm manure and ground rock-phosphate or basic-slag phosphate with the preceding crop is advantageous. Just before seeding, an application of 300 to 600 pounds of **Mixture No. 1** (p. 542) may be harrowed in lightly; on clay soils, less potash can be used. After the first year 200 to 400 pounds of **Mixture No. 2** can be applied, or generous annual dressings of farm manure can be given, together with 100 to 200 pounds of acid phosphate and 50 to 100 pounds of potassium chloride.

About 40 per cent. of the plant-food value of a normal crop of alfalfa is usually contained in the roots. When these decay, they leave the subsoil better fitted for drainage and circulation of air, as well as provide abundance of organic matter.

It should be added that inoculation is generally necessary on soils where neither alfalfa nor sweet clover has ever been grown. For this purpose soil from an alfalfa or sweet-clover field should be used. It is often a good plan to grow a crop of sweet clover on a soil as a preparation for growing alfalfa, especially on poor soils.

Field-peas.—For green-crop manure some variety of Canada field-pea is usually grown. They grow well even on heaviest clays but do best on clay loams. On light soils deficient in moisture, they do not thrive. The crop grows best only in moist, cool weather, such as is common in northern climates during early spring and late fall, and it is, therefore, largely confined to northern states. The field-pea is extensively used in the citrus orchards of California as a winter green-manure or cover-crop. If planted in spring,

the seeding should be made as early as possible. For fall planting, the crop can be started in August or September and make a good growth before freezing weather comes; it will then be ready for use in spring plowing. It can follow such crops as are not removed until September. It has been shown that in two months it is possible to grow a crop of 13 tons an acre, containing about 2 tons of dry matter, with 120 pounds of nitrogen, 35 pounds of phosphoric acid (15 lbs. P), and 120 pounds of potash (100 lbs. K).

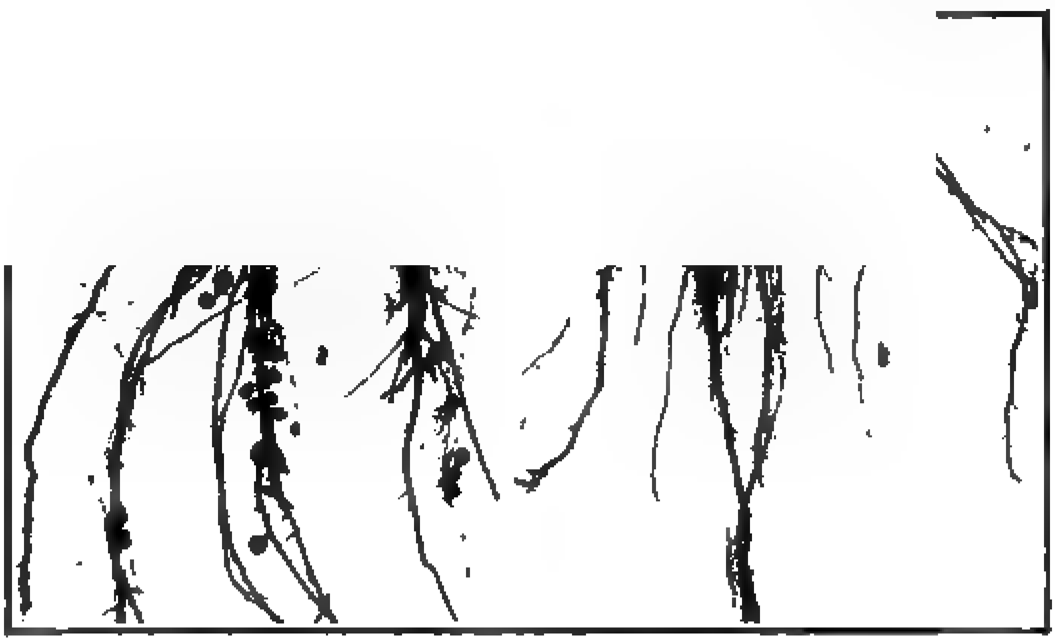
Field-peas make vigorous growth when put into a well-tilled seed-bed, but they will do better than most other leguminous crops on soil less well prepared. From 2½ to 3½ bushels of seed per acre should be used and covered 2 to 4 inches deep. They do better when drilled in than when sown broadcast. On soils not well provided with available plant-food, it is well to apply at seeding 200 pounds per acre of **Mixture No. 1**. For use as green forage and hay, with other crops, see pages 589-592.

Nodules on roots of soy-beans grown second season on same soil. Natural and reduced size. KENTUCKY STATION.

Cowpeas are vine-like annuals more nearly resembling beans than peas; they grow best in warm climates, but have been adapted to cooler climates, some varieties being grown as far north as Massachusetts and Wisconsin. There are several varieties with marked differences, varying from the bush-like, rapid growing and early maturing kinds to those that are distinctly vine-like with stems several feet long.

This crop possesses some prominent characteristics which peculiarly fit it for a green-crop manure in places where

clover and alfalfa are not utilized: (1) It utilizes atmospheric nitrogen and furnishes large amounts of organic matter; (2) it has unusual ability to grow on poor soils and on almost any kind of land that is not too wet; (3) it covers the ground so thickly as to prevent the growth of most weeds; (4) it is a vigorous, rapid and deep-rooted grower; (5) it grows best during the hot months, when it is most important to have the soil covered in order to prevent destruction of nitrifying bacteria; (6) the beneficial effects of the crop, when used as green-manure, last two or three



Roots of soy-beans: *a*, seed treated with bacterial culture; *b*, seed not treated. KENTUCKY STATION.

seasons if followed by such crops as corn, cotton or small grains; (7) in the South two crops a year can be grown on the same soil.

The cowpea plant is very sensitive to cold and should therefore not be planted until danger of freezing is past and the soil has become warm. Cowpeas are often planted between rows of corn at the time of its last cultivation or broadcasted on stubble of small grains. The soil should be put into good tilth, the seeds sown broadcast (1½ to 2 bushels to an acre) and covered about 2 inches deep, or put

in with a grain-drill. When grown for forage or hay or seed, better results are obtained by sowing in drills 20 to 30 inches apart, according to large or small size of variety used.

Soil inoculation is not usually necessary in the South, but in the North has sometimes been found needful, as shown by lack of nodules on roots. On moderately good soils fertilizers are not commonly used. However, on light soils that have been continuously cropped and are low in available plant-food, 200 or 300 pounds of **Mixture No. 1** (p. 542) may be cultivated into the soil before seeding. On clay soils, potash can usually be omitted. Unlike most leguminous plants, the cowpea tolerates a moderate degree of soil acidity.

Alfalfa roots 3 years after seeding. KANSAS STATION.

When grown as a green-manure crop, it can be plowed under in the green state or left as a mulch on the surface until early spring and then plowed under. Generally, the most economical method is to use it as forage and put back the manure. The large amount of foliage makes it difficult to plow the whole crop under satisfactorily. On light soils, especially in warm climates, the whole crop should not be plowed under, since it makes the soil too open for a time. The cowpea is the most important leguminous crop used in the South as a means of soil improvement; and, wherever it can be grown successfully, it is probably the most useful of all crops for this purpose, since it appears to combine nearly all the advantages possible in a green-crop manure. Cowpeas may be raised along with vetch (p. 555) as a cover-crop for orchards or in rotations on sandy soils.

A good crop of cowpeas contains about 2 tons of organic matter an acre, with 75 to over 100 pounds of nitrogen, 20 to 25 pounds of phosphoric acid (8 to 11 lbs. P) and 100 pounds or more of potash (83 lbs. K). About one-third of the nitrogen of the crop is in the roots.

Soy-beans or Japanese peas resemble cowpeas in many ways, but in some respects are more difficult to grow, and the yield is not so large. The adaptation to climates and soils is much the same as for cowpeas. The crop is grown satisfactorily as far north as Massachusetts and Wisconsin, and on soils varying from clay to sandy; but in the northern states well-drained sandy or sandy-loam soil is desirable in order to ripen the crop earlier when grown for seed. The crop withstands drouth and is also able to grow well on rather wet soils. Owing to less rapid and vigorous early growth, soy-beans are more liable to be troubled by weeds than are cowpeas. The plant is sensitive to frost. The general cultural treatment is essentially the same as for cowpeas. In starting soy-beans on new soils, it has often been found that the bacterial nitrogen-gathering nodules are not found on the roots until the soil has been inoculated with soil from a soy-bean field. Treatment with fertilizers is the same as for cowpeas.

Root system of cowpeas near maturity, 111 days after planting KANSAS STATION.

A crop of soy-beans, including roots, may contain as much

as 175 pounds of nitrogen, 45 pounds of phosphoric acid (20 lbs. P) and 115 pounds of potash (96 lbs. K). The results of some experiments appear to indicate that the soy-bean plant is capable of utilizing atmospheric nitrogen to a greater extent than the cowpea crop does.

Velvet beans have been found extremely useful in those portions of the South where warm, moist weather prevails,

ROOTS OF SOY-BEANS, 55 DAYS AFTER PLANTING. KANSAS STATION

as in the Gulf States. It is adapted to light soils, but may be grown on any fairly well-drained soil. The vines, usually 10 to 30 feet in length, may grow as long as 75 feet, making the crop a difficult one to plow under. Yields of 10 tons and more of green matter per acre are reported, with a nitrogen content of 100 to 200 pounds. The same general cultural treatment may be followed as with cowpeas or soy-

beans, with application of 200 or 300 pounds of **Mixture No. 1,** working it into soil just before seeding.

Vetch has been grown successfully as a late-fall green-manure crop. On light, poor soils, it is usually better than cowpeas or soy-beans. Two varieties have been most commonly used, common vetch or spring tare, and hairy or sand vetch. The common vetch is grown in the citrus orchards of California as a cover-crop or winter green-manure crop. In the northern states it is apt to winter-kill. Hairy vetch closely resembles common vetch in general, but is more hardy at low temperatures than any other leguminous plant used as a green-crop manure; thus, in New York it remains green all winter and resumes growing in spring. This hardiness is a desirable quality in the North. It has been found very useful as a cover-crop and winter green-manure in Connecticut on tobacco lands. A combination of cowpeas followed by vetch has been utilized in orchards and crop-rotations, furnishing a maximum amount of organic matter for the soil.

Hairy vetch. Four inoculated plants on left. Four non-inoculated plants on right. ALABAMA STATION.

The hairy vetch may be seeded either from the middle of August to the middle of September, or in spring from the last of April to the middle of May. In corn or cotton fields, it is sown broadcast and worked in with the last cultivation.

Inoculation is usually desirable on new soils. Soil on which garden-peas have been grown can be used for this purpose, if that is more convenient to obtain than soil from a vetch field. On poor land, vetch responds well to appli-

cation of fertilizers; 200 to 400 pounds an acre of **Mixture No. 1** can be used.

TABLE 55—APPROXIMATE AMOUNTS OF PLANT-FOOD CONSTITUENTS IN ONE CROP

Crop	Yield per acre	Water	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
	Pounds	Per cent.	Pounds	[illegible]	Pounds
Alfalfa	20,000	75	120	3[illegible]	100 (83K)
Clover, alsike ..	16,000	82	80	1[illegible]	48 (40K)
" crimson ...	16,000	82	72	1[illegible]	64 (52K)
" mammoth	20,000	80	100	2[illegible]	80 (66K)
" red	12,000	80	66	1[illegible]	60 (50K)
" white	8,000	81	40	1[illegible]	24 (20K)
" sweet	20,000	80	110	3[illegible]	100 (83K)
Field pea	10,000	82	50	1[illegible]	50 (42K)
Cowpea	12,000	84	54	1[illegible]	54 (45K)
Soy-bean.	10,000	75	50	1[illegible]	60 (50K)
Velvet-bean:.....	20,000	75	110	3[illegible]	110 (91K)
Vetch	10,000	84	50	1[illegible]	45 (37K)

P, phosphorus. K, potassium.

In the foregoing table the estimates are made on the basis of what may be regarded as reasonable averages under fair conditions of growth.

CHAPTER XXIX

MEADOWS, PASTURES AND LAWNS

Land on which crops, especially grasses and clovers, are grown for the purpose of making hay is known as *meadow;* it is known as *pasture* when continuously used by stock for grazing. A *lawn* is a piece of land covered with grass and kept cut close, usually near a dwelling. Permanent meadows or pastures are those used continuously for long periods of time; when temporary, the land is occupied with grass from one to three years, ordinarily as part of a rotation. The various kinds of seeds to be used will be determined by the object in mind, whether meadow, pasture or lawn, as well as by soil and climatic conditions. Thus. in a meadow it is important to use plants which reach their best condition for hay-making at the same time; while in pastures such varieties of plants should be used as will furnish a uniform supply of feed from spring to fall, which is accomplished by selecting several different species of plants that reach their best condition for grazing purposes at different periods during the season and which remain in the soil continuously. For lawns, much the same general requirements exist as in the case of pastures, the selection of plants being made with reference to furnishing a dense, velvety, carpet-like appearance when kept closely cut.

The question of keeping land temporarily or permanently occupied with grass must depend upon individual conditions; for example, permanent grass-lands may advantageously be located on hillsides and uplands, very heavy soils, stony land, lowland subject to overflow, swamp land, etc., while on sandy or light soils grasses run out after a short time and only temporary occupation is usually practicable.

MEADOWS

The general tendency among farmers has been to regard hay as a catch-crop with small grains, little attention being given to treatment with plant-foods. Farmers are, however, coming slowly to regard meadows as lands that respond profitably to more particular care. In this connection we will consider the following points: (1) Soil conditions and preparation, (2) use of fertilizers, (3) plants used for meadows.

Soil conditions and preparation.—Soils for meadows may vary widely in character, ranging from heavy clays to sandy loams. On heavier soils, meadows are more easily started and kept permanent, while on light soils difficulty is experienced in getting plants started and they run out more quickly. One of the most important qualifications in soils for permanent meadows is the power to hold a sufficient supply of water.

The popular method of starting a meadow where rain is sufficiently abundant is to seed the grass along with small grains, especially wheat or rye, the seeds of the grasses being usually sown in the fall and those of clovers in the spring. The starting of grasses with an oat crop often proves unsatisfactory. The preparation of soil required for wheat or rye usually suffices for seeding of grasses along with the sowing of the grain. Best results, however, are secured in starting permanent meadows by preparing the land especially for the grass crop and then seeding without grain. The method of really thorough preparation is to plow deep, and cultivate several times very thoroughly for the double purpose of destroying weeds and giving the soil a very fine tilth. This treatment results in making the soil mellow for the easy penetration of the young rootlets and it also tends to increase the amount of available plant-food.

Suggestions on use of fertilizers for meadows.—In supplying plant-food to meadows, some few guiding facts should be kept in mind.

(1) *Presence of calcium carbonate.*—If there is any doubt regarding the presence of enough calcium carbonate in the soil, an application is made while the soil is undergoing preparation for seeding, using 1,000 to 2,000 pounds of burned lump-lime (calcium oxide) or 2 to 3 tons of ground limestone (calcium carbonate) (pp. 379-389). The application may be repeated as a top-dressing on permanent meadows once in four or five years. The calcium carbonate is essential to insure the continued presence of clovers, which contribute air-derived nitrogen as well as utilize plant-food in the deeper portions of the soil.

(2) *Effect of nitrogen.*—Grasses are favorably affected by the application of nitrogen compounds, particularly nitrate. This is in accordance with the characteristic action

Effect of top-dressing grass-land with nitrate of soda. The plot on the left received no nitrate, the center one-third ration, and the one on the right a full ration of nitrate. TENNESSEE STATION.

of nitrogen in promoting vigorous growth of stems and leaves (p. 64), which in meadows are the portions of the plants desired as crop. Meadows benefit especially from application of nitrate early in the spring, when the available nitrogen supply is usually at its lowest and when the nitrifying organisms (p. 204) have not yet begun work in renewing the supply. When clovers are prominent constituents of meadows, less nitrogen needs to be applied than where the vegetation consists wholly of grasses. Heavy applications of nitrogen compounds tend to cause clovers to run out. In case of mixed clovers and grasses, an annual spring appli-

cation as top-dressing on established meadows may contain 12 to 24 pounds of nitrogen equal to about 75 to 150 pounds of sodium nitrate; on timothy and on mixed grasses, double that amount may be used. Frequently nitrate alone gives excellent results, but it is generally better to use it in a mixture with phosphorus and potassium compounds. In applying nitrate alone, it should be very finely ground and thoroughly mixed with three or four times its weight of inert material (p. 532), in order to make uniform distribution easier. Nitrate, when containing small lumps or when unevenly distributed, may burn the vegetation injuriously, though danger of this is at a minimum in early spring applications before the plants have started green growth.

(3) *Use of phosphorus and potassium compounds.*—To insure the continuation of clovers in meadows, there must be a generous supply of phosphorus and potassium compounds. Phosphorus may be supplied in the form of acid phosphate alone or with bone-meal; basic-slag phosphate, and, in case of soils well supplied with organic matter, "floats" may be used. Potassium can be furnished in the form of chloride (muriate). The amount of these constituents will, of course, depend upon the general character of the soil, its previous cropping and fertilizer treatment.

(4) *Use of fertilizers in seeding meadows.*—However accomplished, it is desirable that, previous to seeding grass for permanent meadow, the ground be well provided with organic matter and be free from weeds. When farm manure is used, both of these conditions can be realized by applying fresh farm manure (10 to 12 tons) to the preceding crop, preferably some hoed crop, as corn, for example; or farm manure sufficiently decomposed to destroy weed seeds (p. 337) can be applied directly at the rate of about 8 tons an acre and worked into the soil thoroughly just before sowing seed. In whichever way the manure is used, 250 to 500 pounds of **Mixture No. 1** can be applied per acre just before

or at time of seeding, which will furnish approximately the following amounts of plant-food:

Nitrogen	5 to 10 lbs.	
Available phosphoric acid	20 to 40 "	(9 to 18 lbs. P)
Potash	25 to 50 "	(20 to 40 " K)

When no farm manure is used either by direct application or with the preceding crop, one can apply 400 to 800 pounds of the following:

Plant-food mixture No. 3.—*For use in seeding grass.*

Sodium nitrate	100 lbs.	(15 lbs. nitrogen)
Tankage (6.5—9)*	700 "	(45 " " and 63 lbs. phos. acid, or 28 lbs. P)
Acid phosphate	400 "	(56 " available phosphoric acid, or 25 lbs. P)
Potassium chloride	360 "	(180 " potash, or 150 lbs. K)
Drier (p. 480)	440 "	

* 6.5 per cent. of nitrogen and 9 per cent. of phosphoric acid.

This mixture contains about 3 per cent. of nitrogen, 6 of phosphoric acid (2.6 P) and 9 of potash (7.5 K). An application of 400 to 800 pounds contains approximately the following amounts of plant-food.

Nitrogen	12 to 24 lbs.,	one-fourth soluble
Total phosphoric acid	24 to 48 "	(10 to 20 lbs. P) about one-half soluble.
Potash	36 to 72 "	(30 to 60 lbs. K)

This mixture provides for a small amount of nitrate with the rest of the nitrogen in form to become available during the growing season; the same is true of phosphorus.

(4) *Spring application on established meadows.*—To give grass on an established meadow a prompt and vigorous start early in the growing season, an annual top-dressing early in spring is desirable, either of farm manure or commercial fertilizer. The finer the farm manure, the better it will serve the purpose, since it can more easily work down into the interstices in the soil and grass; it also acts as a mulch in holding water, which is desirable, especially on porous, light soils. When practicable, it may be well to apply manure one spring and the commercial fertilizer the next, alternating from year to year.

When a plant-food mixture is used, it should be relatively

rich in nitrate nitrogen, especially if the growth of timothy is desired. Such a mixture can be prepared by adding 500 pounds of sodium nitrate to 2,000 pounds of **Mixture No. 1** (p. 542), making 2,500 pounds, which, reduced to the basis of one ton, would be as follows:

TWO TIMOTHY PLANTS SHOWING VARIATION LARGELY DUE TO SEED SELECTION. NEW YORK (CORNELL UNIV.) STATION

Plant-food mixture No. 4.—*For early spring use on timothy meadows.*

Sodium nitrate ...	720 lbs.	(108 lbs. nitrogen)
Aci ' phosphate ...	880 "	(123 " available phosphoric acid, or 54 lbs. P)
Potassium chloride	240 "	(120 " potash, or 100 lbs. K)
Drier	160	

This mixture contains about 5.5 per cent. of nitrogen, 6 of available phosphoric acid (2.6 P) and 6 of potash (5 K). Applied at the rate of 400 to 800 pounds per acre, it would furnish the following amounts of plant-food:

Nitrogen	22 to 44 lbs.	
Available phosphoric acid...	24 to 48 "	(10 to 20 lbs. P)
Potash....................	24 to 48 "	(20 to 40 " K)

When it is desired to encourage the growth of clovers in meadows, **Mixture No. 2** (p. 543) should be used at the rate of 300 to 500 pounds an acre.

(5) *Summer application.*—After the grass has been cut, an additional application of fertilizer can be made to promote the second growth. For this purpose, the mixture should contain less nitrogen, since the soil will be in condition to furnish more as the result of summer nitrification and less of the applied nitrogen need be nitrate. These conditions are met by **Mixture No. 3**, of which 200 to 300 pounds can be used.

The amount of fertilizers used may be regulated, to some extent, by the probable crop yield. For example, when, owing to climatic conditions, or poor stand of grass, or any other cause, the yield of hay is practically limited to one ton, it is poor economy to use enough plant-food to meet the needs of a three-ton crop.

ROOT SYSTEMS:
Orchard grass. Bromus inermia.
KANSAS STATION.

Plants used for meadows.—In selecting plants to use for meadows, one is governed by local soil and climatic conditions, duration of meadow, and by the character of the grasses as food for farm animals. In the eastern states, the following are partial to moist soils: Fowl meadow-grass, Italian rye-grass, meadow fescue, meadow foxtail, red-top. On heavy loams and clays, alsike clover and timothy hay are suited, to which for pasturage may be added Kentucky blue-grass, white clover and meadow fescue. On average soils, timothy, red-top, Kentucky blue-grass and red clover are very useful.

When land is to be used only two or three years as meadow,

those plants should be selected that attain full growth quickly, such as red and alsike clovers, timothy, red-top and orchard grass; for permanent meadow, the following may be added to these: Alfalfa, Kentucky blue-grass, meadow foxtail, meadow fescue, Canada blue-grass, etc. Generally, those kinds are selected that grow strong and tall, as timothy, red-top, tall fescue, alsike and red clovers. Largest yields most commonly come where only one or two kinds are grown. In the following table, mixtures of seeds for meadows are given as suitable for those sections where the plants can be grown. The figures denote in each case the amount of seed to be used for one acre.

TABLE 56—MIXTURES OF SEEDS FOR MEADOWS

Kind of grass	Temporary meadows 1-3 years	Permanent meadow	Permanent meadow	For very poor land	For poorest acid soils	Permanent meadow	Permanent meadow
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Timothy	15	12	15	10	—	8	—
Red clover	—	4	7½	—	—	4	4
Mammoth red clover	6	—	—	—	—	—	—
Alsike	4	2	—	4	—	2	—
Red-top	—	—	7½	5	15-20	2*	13
White clover	—	—	—	—	—	—	—
Kentucky blue-grass	—	—	—	—	—	2*	—
Tall meadow fescue	—	—	—	—	—	—	9
Orchard grass	—	—	—	—	—	—	18

*Most prominent after a few years.

The properties of the leguminous plants used for making hay have been discussed in the previous chapter, and we will here add a brief description of some of the grasses most commonly used in permanent meadows and pastures.

(1) *Timothy*, though primarily a plant for hay production, is very commonly used in pastures, because the seed is inexpensive and it produces a fair crop the first year. In a few years it usually runs out in permanent pastures. Timothy is easily adapted to good crop-rotations. It grows best in good soils and with plenty of rain; it is responsive

to generous use of fertilizers when soil conditions are good and moisture is plentiful.

(2) *Red-top*, while not making as valuable a hay as timothy, is very useful, because it grows on soils on which timothy will not grow, as, for example, on soils that are wet or acid or lacking in available plant-food. It produces hay or pasture the year after being sown.

(3) *Kentucky blue-grass*, while of little value for hay, is of the highest value as a pasture grass. It is not usually seeded alone, since it requires two or three years to reach full growth. It begins growing early in the season and heads early; it also grows well in autumn, but makes poor growth in hot weather.

(4) *Tall meadow fescue* does well on good land; it takes about three years to form a good sod and is, therefore, adapted only to permanent grass-land.

Root system of Kentucky blue-grass. KANSAS STATION.

(5) *Orchard grass* is tall; it grows best on rich, deep soils, but it makes fair growth on poor soils. On account of its deep root system, it withstands drouth well. It has the disadvantage of growing in bunches and making a very rough sod, and also it must be cut near blossoming time to make good hay.

(6) *Perennial rye-grass* does best on stiff, wet soils, as on marshy land; it is a good grass for pastures.

(7) *Red fescue* is found in lawn and pasture grasses. It grows on dry, light soils and rather barren uplands; it makes a fine, close sod and also does well in shady places.

(8) *Rhode Island bent-grass* is much like red-top. It is especially valuable in lawns.

PASTURES

Probably no portion of farms has been so generally neglected as the pasture-land. In most cases no attention is paid to supplying plant-food further than the incidental droppings of grazing animals, and grazing is often begun too early and allowed to become too close. This treatment results in destruction of perennial grasses, loss of organic soil matter, decreased power of retaining moisture, and the substitution of worthless weeds for valuable forage plants; in other words, the pastures "run out." It has been shown that permanent pastures of value can be secured if proper attention is given to the conditions of soil preparation, seeding, fertilizing and subsequent care. Generally speaking, in starting a permanent pasture, the same kind of care should be taken in relation to these conditions as described above in starting permanent meadows. After the first year light top-dressings of good farm manure may be applied to advantage early in spring, or 200 to 400 pounds of one of the mixtures of commercial plant-foods given for meadows. (pp. 560-563). Farm manure should be applied to poorer portions of the field, especially to bare spots. Pastures should be limed, especially where moss-grown areas appear; it is better, however, not to wait for such symptoms, but to lime at the start and then systematically every four or five years where any doubt exists regarding the need of calcium carbonate. A liberal application of seed every two or three years, especially along with farm manure, mowing of weeds once or twice a year, before blooming, and occasional harrowing, will aid in keeping the pasture permanently useful. If practicable, it is a good plan to go over the pasture in spring with a harrow in order to distribute more evenly the animal droppings. In case of pastures that are badly run down, the most effective method of renovation is to plow up the sod and start anew, when this is practicable.

In seeding permanent pastures, the plants should be selected with reference to getting those that will combine

to give a continuous growth of grass through the season; some should mature early to get ahead of weeds; some should contribute to making a close, dense turf; some serve as a protection to prevent injury from the treading of stock. Various mixtures of plants have been used to secure these different objects and some of them are given in the following table:

TABLE 57—MIXTURES OF SEEDS FOR PERMANENT PASTURES

Kind of plant	Hay two yrs., followed by pasture on good land	Permanent pasture	Permanent pasture	Temporary pasture	Pasture on wet land	Pasture on light, sandy soil	Pasture on very poor acid soil	Pasture on poor land	Mixture for sowing on old pastures
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs,	Lbs.	Lbs.	Lbs.	Lbs.
Timothy	10	8	—	10	—	—	5	8	2-3
Red clover	4	6	—	8	—	—	—	6	2-3
Alsike	3	3	—	4	8	—	5	3	1
Red-top	—	—	8	—	14	10	5*	4	2
White clover	2*	1-2*	4	—	—	2	2*	1	—
Kentucky blue-grass	3*	4*	8	—	—	8	—	—	4
Meadow fescue	2	1-4	—	—	—	—	—	—	3
Orchard grass	2	1-4	—	—	—	—	—	—	—
Alfalfa	2	—	—	—	—	—	—	—	—
Perennial rye-grass	—	—	9	—	12	—	—	—	—
Red fescue	—	—	3	—	—	20	—	—	—
Creeping bent-grass	—	—	—	—	6	—	—	—	—
Canadian blue-grass	—	—	—	—	—	—	—	4	—

*Most prominent after a few years.

LAWNS

In the making and maintenance of lawns, haphazard and inefficient methods have too often been the rule, while even more pains should be taken, if possible, than with meadows or pastures. Private lawns are usually small and easily permit extra attention; the main difficulty has been lack of information in regard to the proper methods of starting and maintaining them. A perfect lawn, either private or public, is a rare sight. We will consider the subject in relation to (1) character of soil, (2) preparation and fertilization of soil, (3) starting the growth of grasses, (4) care and fertilization after seeding, (5) grasses to use for lawns.

Character of lawn soil.—The best soil conditions for lawns are essentially the same as for meadows and pastures, that is, a soil containing a considerable proportion of clay, with a tendency to be heavy and compact (not light, loose and sandy), rather retentive of moisture, keeping moderately moist without becoming too wet. These conditions are best found in a decided clay loam, or a sandy loam resting

KENTUCKY BLUE-GRASS AT HOME

Woodland pasture at Ashland, the home of Henry Clay. KENTUCKY STATION.

on a clay subsoil. Soils used for lawns are seldom normal often consisting of mixtures of building débris, surface soil and subsoil from excavations. We will first consider methods that should be employed in making a lawn soil. Where filling to a considerable depth is required, no kind of coarse material, like bricks, stones, etc., should be used in the upper 4 feet. The subsoil should be made of moderately heavy clay. When the filling material varies in texture, the heaviest is placed

first, evenly distributed and over this an even layer of lighter subsoil material, care being taken to use only soil mellow enough to permit roots to penetrate deeply for water. For the upper layer of 6 to 12 inches, only surface soil of good productive capacity should be used, preferably that obtained from a cultivated field; this should be lighter than the subsoil but not radically different in general character.

Preparation and fertilization of lawn soil.—Attention must be given to tillage and treatment with lime, organic matter and special plant-food mixtures. The soil should be thoroughly plowed or spaded to a depth of 8 to 10 inches and then carefully fined at the surface by raking or harrowing; it is then compacted by means of a lawn or field-roller, after which the surface is again loosened by a rake or harrow, thus making a seed-bed suitable for fine seeds.

When possible, it will be found most desirable to begin the preparation and treatment of the soil the season before seeding to grass, especially in case of soils in any way abnormal. The following plan is suggested: Plow the soil, apply and harrow in 1,000 to 2,000 pounds of quicklime that has been slaked to a fine powder; after 2 or 3 weeks harrow in well-decomposed farm manure at the rate of 8 or 10 tons an acre, if obtainable, working it in thoroughly. With the manure may be added 1,000 pounds of ground rock-phosphate. Then sow clovers, cowpeas, soy-beans or some leguminous crop suitable to local conditions. When this has made a good growth, plow it under. This treatment insures abundance of organic matter and calcium carbonate and also aids in destroying weeds. The following season the soil is put into condition for a good seed-bed as described above, after previously working in any one of the fertilizing mixtures indicated for meadows (p. 560). When the soil is not thus treated the season before seeding to grass, the following method is used, when good farm manure can be obtained: Lime the soil as directed above, apply 10 to 15 tons of well-decomposed farm manure and in addition 200 to 400 pounds of **Mixture No. 2** (p. 543).

Starting the growth of lawn grasses.—When the seed-bed is perfected, grass-seed is sown broadcast in amounts depending on the kinds used; the seed is then covered less than half an inch deep by harrowing or raking. In order to insure a uniform distribution of seed a second sowing should be made, going at right angles to the first sowing with the same amount of seed, and covering as before. The ground is then compacted by a 300-pound lawn roller. Spring sowing is generally more successful than fall sowing in the Eastern and Middle states. When fall sowing is done in this region, late August or early September is usually best. If seed can be sown before showers, prompt germination will be insured.

Care and fertilization of lawn after seeding.—When the grass has become of sufficient height (3 or 4 inches), it is clipped by a lawn-mower, and this should be repeated from time to time. The grass is never allowed to go to seed. Ordinarily, clipping within 2 inches of the ground is about right. It is desirable early in each spring to go over the lawn with a heavy roller as soon as it is dry enough.

Frequently, trouble is experienced with deep-rooted weeds, such as dandelions, plantains, etc.; when these persist it is necessary to remove them with a trowel or knife; but, when the weeds crowd out most of the grasses, then it is least trouble to plow up the ground and start anew.

One popular method of fertilizing established lawns is to spread over the surface in late fall or early winter or early spring a thin coating of well-decomposed, finely divided farm manure, raking it in as close to the surface of the soil as possible. More recently there have come into use some stock-yard products, such as dried sheep manure, cow manure and pig manure (p. 257). In drying, these materials are heated high enough to destroy weed-seeds, which makes their use more desirable than that of many farm manures; moreover these dried manures are in finely divided condition. This can be used as a spring application at the rate of

1 to 2 ounces per square foot, or nearly $1\frac{1}{2}$ to 3 tons an acre. The plant-food in them is fairly high in cost compared with many of the unmixed fertilizing materials. Bonemeal or bone-flour can be applied as a top-dressing in spring, sprinkling lightly over the surface. The most effective single plant-food material is sodium nitrate; when applied alone, this can be used in early spring at the rate of 100 pounds an acre. Two or three additional applications during the season, each at the rate of 50 pounds an acre, will be found

Crop of clover on land treated with calcium, nitrogen, phosphorus and potassium compounds. Yield of hay per acre, 6,560 lbs. IOWA STATION.

effective. In applying sodium nitrate care should be taken to distribute it uniformly and in finely powdered form. In order to apply it evenly, it can be mixed thoroughly with any fine, dry material (p. 532). When put on in small lumps, nitrate will burn the grass seriously. It is an excellent plan to scatter nitrate just before a shower or to sprinkle the lawn right after the application, or, still better, to dissolve it in water at the rate of one ounce or a tablespoonful of nitrate in 3 or 4 gallons of water and distribute this over a space about 5 feet square with a sprinkler. On the whole, however, better results may be expected from the use of

a mixture of plant-foods, provided sufficient care has been taken to put the soil in the best possible physical and chemical condition before putting in the seed. **Mixture No. 4** is well adapted for use on lawns, applying first in early spring at the rate of 800 pounds an acre or about 3 ounces for 1 square yard. Two or three additional smaller applications can be made at intervals during the season, using 100 or 200 pounds an acre.

Grasses to use for lawns.—Grasses adapted to lawn-making possess the following requirements: (1) They must make a close turf, as in case of grasses that have creeping rootstocks, short joints and produce abundance of long, narrow leaves about the crown of the plant. (2) They must possess a pleasing color not easily affected by changes of season. (3) They must resist drouth. (4) They must respond promptly to the marked changes from cold to warm seasons. (5) They must bear without injury continuous clipping by lawn-mowers. In general, best results are obtained by a mixture of different grasses, because it is not often that soil and climatic conditions are favorable enough to develop a single grass into a perfect lawn. The grasses best adapted to lawns in the eastern and northen states are Kentucky blue-grass, red-top, Rhode Island bent-grass, creeping bent-grass and white clover, all of which make a dense, deep sward. White clover is very desirable upon sandy soils and in spring seeding, because it covers the ground quickly and comes back quickly after severe drouths.

Care must be taken to obtain pure grass seed of such vitality that most of it will germinate. The amount of seed to use in lawn-making should be sufficient to insure a thick stand and prevent the growth of weeds. When used in combination, 2 to 3 bushels an acre should be sown of such grasses as blue-grass, bent-grass and the fescues. Blue-grass alone may be sown at the rate of 2 bushels an acre; when white clover is added to the foregoing varieties, a peck per acre should be used. . . . .

As an illustration of a mixture of seeds for lawns, we give the following:

Timothy	10 pounds
White clover	5 "
Red-top	10 "
Kentucky blue-grass	20 "
Rhode Island bent-grass	5 "
Creeping bent-grass	5 "

TABLE 58—APPROXIMATE AMOUNTS OF PLANT-FOOD CONSTITUENTS IN ONE TON OF HAY FROM DIFFERENT GRASSES

Crop	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
		Lbs.	Lbs.
Kentucky blue-grass	24 lbs.	8 (3.5 P)	31 (26 K)
Meadow fescue	19 "	8 (3.5 P)	40 (33 K)
Orchard grass	24 "	7 (3.1 P)	35 (29 K)
Perennial rye grass	23 "	11 (4.8 P)	30 (25 K)
Red-top	24 "	7 (3.1 P)	20 (17 K)
Timothy	25 "	11 (4.8 P)	20 (17 K)
Mixed grasses	30 "	8 (3.5 P)	27 (22 K)

P, phosphorus. K, potassium.

CHAPTER XXX

CEREAL AND GREEN-FORAGE CROPS

Under this head we include those crops that are most commonly grown for grain, chief among which are (1) corn, pop-corn, (2) wheat, (3) rye, (4) oats, (5) barley, (6) buckwheat, (7) millet and (8) sorghum.

Most of these crops are used also to a greater or less extent as green forage, being cut before maturing and fed directly to animals; this method of feeding is commonly known as "soiling" and the crops so used are often called soiling-crops. They are of special importance in connection with milk production, being used to supplement, or even to take the place of, pastures, and also to furnish succulent food during winter. Cultivable land can generally be more profitably used in this way than for pasturage. The chief qualities desired in a green-forage crop are succulence, palatability and comparatively large yield in a moderately short growing period. Some of these crops are also used as pasturage and hay and as green-crop manure. We shall, as a matter of convenience, consider the conditions of crop treatment for each of these uses (grain, green forage, pasturage, hay, and green manure), in so far as they apply in case of each crop. Generally speaking, the conditions of soil and tillage are essentially the same, for whatever purpose the crop is grown; some variations occur in respect to the variety and amount of seed and the treatment with fertilizers, according as the crop is grown for one purpose or another.

While the cereal crops vary considerably from one another in their feeding powers, period of growth and character of root systems, all of them require for satis-

factory yields good seed, and most of them good soil, good culture and a good supply of available plant-food. Abundance of organic matter and calcium carbonate is desirable.

In connection with each of the crops mentioned above we shall consider the following points: (1) Crop rotations, (2) soil and preparation, (3) fertilizers, (4) seeding, (5) cultivation.

CEREAL AND GRASS PLATS. TENNESSEE STATION

Corn.—The corn crop is one of special value because, where grown under favorable conditions of soil and climate, it is capable of producing considerably more food per acre than does any other grain; and, moreover, the crop is extremely useful not only for grain but as green forage and in other ways.

(1) *Crop-rotations for corn.*—Among rotations in common use, the following will serve as illustrations:

(a) Six years: Corn, 2 years; wheat or oats, 1 year; timothy and clover, 3 years; this is common in the so-called corn-belt.

(b) Four or more years: Corn, 1 year; oats, 1 year; wheat, seeded with timothy and clover, maintained 1 to 3 years; this is common in the North, outside of the corn-belt.

(c) Three years: Corn, 1 year; oats, in fall, 1 year; cowpeas and cotton, 1 year; this is much used in cotton-growing sections.

(2) *Soil and preparation.*—For whatever purpose grown, the best soils for corn are rich, porous, well-drained, warm loams, that do not bake during drouth, though good crops are obtainable on a great variety of soils, ranging from light, sandy loams to heavy clays. Abundance of organic matter and the presence of calcium carbonate are essential.

When corn follows grass, a common form of rotation, it is well to plow in the fall; spring plowing, when necessary, should be done as early as conditions permit. The depth of plowing should usually not exceed 6 or 7 inches. The soil should be well cultivated to a sufficient depth to insure mellowness, warmth, and circulation of air, conditions essential to promote quick and complete germination of seed and rapid, early growth of plants.

Root system of corn, showing distribution of roots between two hills of level-planted corn, 65 days after planting. KANSAS STATION.

(3) *Fertilizers.*—In discussing the question of plant-food supply, the following facts must be taken into consideration: (a) The crop makes most of its growth after hot weather begins, when the process of nitrification (p. 204) is most active. (b) The period of growth is prolonged compared with that of other common cereals. For these

reasons, corn crops can utilize organic nitrogen supplied in the form of farm manure, leguminous green-crop manure, bone-meal, dried blood, meat tankage, fish-scrap, cottonseed-meal, etc. (c) Therefore, corn crops, if well supplied with organic nitrogen, do not require the application of nitrate except in small amounts, sufficient to supply the early needs of the young plants while their root system is limited in reach and before nitrification actively begins. (d) It is, however, desirable that generous amounts of soluble phosphorus and potassium compounds be furnished. (e) Farm manure can be applied to excellent advantage on corn crops, for whatever purpose grown. It is best applied, if coarse and fresh, in fall or winter on sod at the rate of 8 to 10 tons an acre. When applied in spring directly to the crop, it is usually better to use partly decomposed manure especially in case of lighter soils, putting it on the plowed ground and harrowing in thoroughly before planting seed. When corn follows a leguminous crop, it is well to apply in any case, if possible, 2 or 3 tons of farm manure an acre in order to carry into the soil micro-organisms that will hasten the decomposition of the green-manure crop, making its plant-food constituents available during the growing period of the corn crop. In the case of soils deficient in organic matter and available plant-food, treatment with farm manure or leguminous crops or a combination of the two should be regarded as absolutely essential for a successful crop of corn.

When a corn crop is grown under favorable soil conditions, with an abundance of leguminous green-crop manure or farm manure, the following mixture is suggested at the rate of 250 to 500 pounds an acre.

Plant-food mixture No. 5.—*For corn on soils rich in organic matter.*

Sodium nitrate........	400 lbs.	(60 lbs. nitrogen.)
Acid phospate	1150 "	(160 lbs. available phosphoric acid, or 70 lbs. P)
Potassium chloride	200 "	(100 lbs. potash, or 83 lbs. K)
Drier (p. 480)	250 "	

This mixture contains about 3 per cent. of nitrogen, 8 available phosphoric acid (3.5 P) and 5 potash (4.2K) and in applications of 250 to 500 pounds furnishes the following amounts of plant-food:

Nitrogen......................	7.5 to 15 lbs.
Available phosphoric acid......	20 o 40 lbs. (9 to 18 lbs. P)
Potash......................	12.5 to 25 lbs. (10 to 20 lbs. K)

On light soils, which are not well supplied with organic matter, a more liberal application of fertilizer should be used, 400 to 800 pounds, in which part of the nitrogen is nitrate and part in less quickly available forms. The foregoing mixture modified by addition of tankage containing 6.5 per cent. of nitrogen and 9 of phosphoric acid (4P), gives the following mixture having the same percentage composition as the foregoing:

Plant-food mixture No. 6.—*For corn on soils deficient in organic matter.*

Sodium nitrate.......	100 lbs.	(15 lbs. nitrogen)
Tankage (6.5N—$9P_2O_5$)	700 "	(45 " nitrogen and 63 lbs. phos. acid, or 28 lbs. P)
Acid phosphate	700 "	(98 " available phosphoric acid, or 43 lbs. P)
Potassium chloride....	200 "	(100 " potash, or 83 lbs. K)
Drier (p. 480)........	300 "	

As a partial source of supply of slowly available phosphoric acid, one can apply once in 4 or 5 years 1,000 pounds of finely ground rock-phosphate, provided there is in the soil a generous supply of decaying organic matter, furnished by farm manure or green-crop manure.

In regard to the method of distributing fertilizer, some broadcast it, some apply it with the seed in the hill, and some by machines which distribute it in two rows on opposite sides of each row of corn and several inches away from the seed. This last plan is probably the best when the principal object is for the use of the plants during early growth. When the object is for use throughout the season, broadcasting is probably better. When put in the hill in contact with the seed, a concentrated fertilizer like the above may injure the seed (p.

532). The root system of the corn plant is such that fertilizers, when intended for use during the growing season, are most serviceable if uniformly distributed. In the course of a couple of months after planting, the roots extend not only deep into the soil but horizontally in every direction, completely underlying the surface and filling the soil below the cultivated layer.

(4) *Planting.*—The amount of seed used ranges from 6 quarts of seed up, depending largely upon the character of the soil, more being used on good than on poor soils. When planted in hills on very fertile soils, the hills may be 2½ to 3 feet apart each way and 3 or 4 kernels in a hill; on poorer soils, the hills and rows should be farther apart. Too thick planting is undesirable, because in dry spells loss of soil moisture by evaporation through the plant leaves is likely to be so great as to injure the crop. The depth of planting is usually between 1 and 3 inches.

(5) *Cultivation.*—Soon after planting in rows, the surface of the soil is cultivated to a depth of 2 or 3 inches to keep weeds down and to form an earth mulch to retain soil moisture (p. 155). When the plants are 3 or 4 inches high, they may receive one or two ordinary cultivations to a depth of 3 or 4 inches, after which the cultivation must be shallow enough to avoid injury to the feeding-roots. The frequency of cultivation depends on weather conditions. Cultivation may be advantageously continued as long as it is convenient to go between the rows.

Corn as green-forage crop.—When corn is grown as a green-forage crop, whether for immediate use or as ensilage, the object is a rapid growth and a large yield of succulent stalks and leaves in comparison with ears. The character and conditions of soil preparation and cultivation are the same as in case of corn grown for grain. For green forage, a heavier application of nitrogen is permissible.

One can use the following mixture, which is the same as **Mixture No. 5** with tankage added and acid phosphate decreased:

Plant-food mixture No. 7.—*For corn silage and green forage.*

Sodium nitrate	400 lbs.	(60 lbs. nitrogen)
Tankage (6.5N—9P_2O_5)	650 "	(39 " nitrogen and 60 lbs. phosphoric acid, or 26 lbs. P)
Acid Phosphate	750 "	(105 " available phosphoric acid, or 46 lbs. P)
Potassium chloride	200 "	(100 " potash, or 83 lbs. K)

On soils rich in organic matter this mixture can be applied at the rate of 250 to 500 pounds an acre, and on soils poor in organic matter at the rate of 400 to 800 pounds. This mixture contains the same percentages of phosphorus and potassium as mixtures 5 and 6 and about 5 per cent. of nitrogen, instead of 3, the additional amount being in the form of tankage, which becomes available gradually during the growing season. The different amounts suggested for application contain the following amounts of plant-food:

Application Lbs.	Nitrogen Lbs.	Total phosphoric acid. Lbs.	Available phosphoric acid. Lbs.	Potash Lbs.
250	12.5	20 (9 P)	13 (6 P)	12.5 (10 K)
400	20	32 (14 P)	21 (9 P)	20 (16.5 K)
500	25	40 (18 P)	26 (12 P)	25 (20 K)
800	40	64 (28 P)	42 (18 P)	40 (33 K)

Corn is planted more thickly when grown as green forage. The thicker the planting, the smaller will usually be the number or size of ears per stalk. In order to obtain ears about one-half full size, 11 to 14 or more quarts of corn, according to size of kernels, are commonly used per acre, when the rows are about 3½ feet apart and the separate stalks in the row 6 to 8 inches apart. When planted in hills, on very fertile soil, the hills may be 2½ to 3 feet apart each way, with 3 or 4 kernels in a hill.

When the corn-growing season extends from the first of May into October, two crops of corn can usually be grown for green forage. After the first crop is removed,

the ground is harrowed deep without plowing, as preparation for planting; this leaves the soil in condition to promote quick germination and rapid early growth, which is important in order to avoid danger from possible early frost. Treatment with fertilizer and tillage is the same as with the first planting.

When a constant supply of green-forage corn is desired, plantings are made in succession, 2 or 3 weeks apart, in amounts to meet one's needs; or one may plant early and late varieties.

In some cases, corn is sowed broadcast with the purpose of having only green forage without any ears, to use especially in time of drouth, which is apt to come some time in August or September. In such cases, comparatively large amounts of seed are used. A fertilizer richer in nitrogen, like **Mixture No. 7**, can be well used in such cases, or if the growth is to be pushed very rapidly **Mixture No. 4** is useful. Apply at the rate of 200 to 500 pounds or more per acre.

Pop-corn is now grown as a field crop. The conditions of soil, culture, feeding, etc., are essentially the same as for sweet corn (p. 631).

Wheat.—This important crop is adapted to a great variety of climatic and soil conditions. The kind of seed used, the methods of rotation, tillage, fertilization and seeding depend upon local conditions, especially climatic. While wheat is grown mostly for the grain, it is sometimes used as a green-forage crop (p. 584). The particular points to which we shall give attention are: (1) Rotations, (2) soil and preparation, (3) fertilizers, (4) seeding.

(1) *Crop-rotations for wheat.*—Continuous growth of wheat on the same soil has been proved to be disastrous to soil fertility in the course of years. The kind of rotation used varies with local soil and climatic conditions and with the special kind of farming practiced. The fol-

lowing rotations are typical ones in common use where they are practicable:

(a) Three years: Corn, wheat, clover; or potatoes, wheat, clover.

(b) Four years: Corn, oats, wheat, clover.

(c) Five years: Corn, oats, wheat, timothy and clover 2 years.

(d) Five years: Corn, 2 years; oats, wheat, clover (used in corn-belt).

(2) *Soil and preparation.*—Wheat does best on well-drained rich clays and heavy loams, but good yields are given on a great variety of soils, even on light soils when moisture is not deficient. An abundance of organic matter is essential for good crops of wheat.

It is necessary that attention be given to proper preparation of soil in the way of tillage. General experience shows that it is best to plow the soil as soon as practicable after the preceding crop has been removed, harrowing after each rainfall. This treatment compacts the soil, prevents weeds going to seed, retains moisture, and puts the soil in fine tilth. The depth of plowing varies from 4 to 8 inches according to special conditions; the aim must be to make the upper layer of 3 to 4 inches mellow, in order to insure prompt germination of seed and rapid early growth. On light, mellow soils, the ground may be only harrowed for seeding, especially when following potatoes or corn. On light soils the seed-bed may be rolled. For spring wheat, fall plowing appears to give best results.

(3) *Fertilizers.*—Among the general methods of feeding the wheat crop, we mention the following: (a) Nitrogen is supplied in part by a leguminous crop as part of the rotation, whether grown as green-manure crop, cover-crop, green forage or hay. The particular leguminous crop used depends on local conditions. (b) This is usually followed by some crop as corn, which can utilize

the plant-food contained in the green crop; and a few tons of farm manure, when obtainable, can with advantage be applied to the leguminous crop and plowed under in late fall or early spring. (c) In some cases, commercial fertilizer may be applied to the preceding crop, in addition to farm manure or green-crop manure, in amounts and forms that will leave some plant-food for the wheat crop following. (d) Generally, the best plan is to utilize farm manure, if fresh and coarse, or green-crop manure for the crop or crops preceding and to apply commercial fertilizer directly to the wheat crop. (e) When farm manure is used directly for the wheat crop, it should preferably be well-decomposed, if used in considerable amounts, especially where rainfall is apt to be deficient; it is well harrowed into the soil before seeding. While the use of 20 or 30 tons of farm manure an acre is sometimes advised, this refers to soils deficient in organic matter and where green crops are not used. About 8 or 10 tons every 4 or 5 years will suffice where a good system of rotation is used. Farm manure is preferable on heavy soils. In some cases, when well-decomposed and in fine condition, farm manure is applied after wheat is sown. (f) In many cases, the chief reliance in feeding the crop is placed upon commercial fertilizers, usually a complete fertilizer being used, though in some cases phosphorus in the form of acid phosphate is used alone for a time with good results, especially on clay soils that are well supplied with nitrogen by means of leguminous crops or farm manure.

In feeding the wheat crop, it is found on most wheat soils that the application of nitrogen and phosphorus is more often called for than potassium, but, in the absence of definite information gained by experience, it is best to assume the need of a small amount of available potassium and to make use of a complete fertilizer. When one is using a good crop-rotation, an application of 200 to 400

pounds of **Mixture No. 5** (p. 577) is suitable. On soils deficient in organic matter, **Mixture No. 6** (p. 578) can be used at the rate of 400 to 800 pounds.

In the case of wheat crops that do not appear to have wintered well or in case of light soils, an early spring application of 75 to 150 pounds of sodium nitrate as a top-dressing will usually prove beneficial in giving the crop a vigorous, early start. At this time, the nitrate supply in the soil is apt to be at its lowest. This is applied broadcast, diluted with some fine inert material, (p. 532) about as soon as the plants begin to show signs of starting growth.

For wheat crops fertilizers are usually applied evenly by an attachment which distributes the fertilizer at the time of seeding.

In case of need of liming, the application is better made with some crop preceding wheat.

(4) *Seeding.*—In moist soils, seed should be covered about 1 inch, and in light, dry soils 2 to 3 inches. The amount of seed used per acre varies with soil, climate, quality and variety of seed, time of seeding, etc. Less seed is used in case of early seeding, good seed-bed, fertile soil, when drilled, where winters are mild, or when seed is small. The amount most commonly used varies from 6 to 8 pecks. The time of seeding winter wheat should be early enough to give the crop a good start before freezing weather begins. Spring wheat is put in as early as seasonal conditions permit.

Wheat as green forage.—Wheat is sometimes grown as green forage, being cut and fed at about the heading-out stage. The conditions of treatment are, for the most part, the same as when the crop is grown for grain except that the seeding should be a little earlier. Treatment with fertilizers should be the same, except that somewhat heavier application of nitrogen is permissible **(Mixture**

No. 7, p. 580), and early spring top-dressing with 100 to 150 pounds of sodium nitrate is generally desirable, the application being made when the foliage is dry and as soon in spring as active growth appears.

Wheat is sometimes used for pasturage and gives excellent results when not cropped too close early in the season. When cut just in full head, and carefully cured, wheat makes very satisfactory hay.

Rye is useful as grain, as green forage, as hay, as pasturage and as green-crop manure. It has a wider range of adaptability to climatic and soil conditions than any other cereal crop. In many of the general conditions affecting its growth, it closely resembles wheat.

(1) *Crop-rotations for rye.*—In general, rye takes the same place as wheat in crop-rotations (p. 498). On account of its hardiness, it is of special value in connection with the seeding of grass and clover, particularly in northern climates.

(2) *Soil and preparation.*—Rye grows on soils that are too poor for other cereals and it will stand more neglect than other cereals. It does best on lighter, rich, well-drained loams and is adapted to many sandy soils. It is not adapted to wet soils or heavy clays. For best results the preparation of the soil should be the same as for wheat (p. 582); it repays good culture.

(3) *Fertilizers.*—Commonly, fertilizers are not used extensively with rye but their use will often be found profitable. The same treatment applies as to wheat. Excessive application of nitrogen is to be avoided, because it results in early lodging, discolored straw, and shrunken grain.

(4) *Seeding.*—Winter rye is generally used; the seeding is made at a time in the fall early enough to enable the crop to get a good start before winter, especially on poor soils. Light soils may be rolled after seeding. Drilling

seed is better than broadcasting. On poor soils one uses 3 to 4 pecks of seed and twice as much on better soils.

Rye as green-forage crop possesses several marked advantages; it is hardy, produces rapid growth early in season ahead of other crops and is very palatable. In the South, it furnishes 3 or 4 cuttings during fall and winter. The soil should be prepared the same as when grown for grain. The treatment with fertilizers is the same as for wheat grown as green forage (p. 584), generous

DRY FARMING IN MONTANA. FALL RYE. MONTANA STATION.

nitrogenous fertilizing being desirable, especially in early spring. In seeding for forage, 2 to 3 bushels of seed should be used.

Rye may be used as pasturage. It may be used for light early spring pasturage, or, when started early enough, for light fall pasturage, without injuring the crop for grain. Rye is used sometimes as ensilage, being cut when headed out fully, and allowed to wilt slightly before

putting in silo. When cut just before full heading out, it makes good hay, if cured properly.

Rye as green-crop manure.—Rye is of special value as a cover-crop for fall and winter use. It has the advantages (a) of being adapted to use late in the season following other crops, (b) of growing rapidly, (c) of being hardy in winter and (d) of making rapid growth in early spring, which can be plowed under in time for the use of various crops, such as potatoes, corn, etc. In the North, it can be utilized as a cover-crop in cornfields, furnishing late fall and early spring pasturage, after which it can be turned under as green manure. While it is useful in furnishing organic matter to soils, it does not, like clover and other leguminous crops, make use of atmospheric nitrogen; it gives back to the soil only the plant-food constituents that it has used in its growth. It is of special value in furnishing organic matter on poor, light soils where leguminous crops do not grow, and is often so used as a preliminary step in preparing such a soil for the subsequent growth of a leguminous crop.

Oats.—The oat crop, besides its value for grain, makes excellent green forage and hay. Oats are grown with peas or vetch for forage. The oat crop is adapted to a cooler climate than is corn, wheat or barley. The oat crop requires much water and is therefore adapted to a moist climate. The growth of the crop is rapid and the amount of straw in relation to grain is large in comparison with wheat, rye, etc.

(1) *Crop-rotations for oats.*—The following rotations serve to illustrate different forms that are typical in different sections:

(a) Four to five years: Corn, 1 year; oats, 1 year; wheat, 1 year; timothy and red clover, 1 to 2 years. Used in winter-wheat sections.

(b) Three to six years: Corn, 1 to 2 years; oats, 1

year; timothy and red clover, 1 to 3 years. Used in corn-growing sections that are not adapted to wheat.

(c) Three to four years: Corn with cowpeas, grown between rows and harvested for grain, 1 year; oats, followed by cowpeas used as hay, 1 year; cotton, 1 to 2 years.

(2) *Soil and preparation.*—The character of the soil may vary much more for oats than for any other cereal. In general, the soil should be fairly moist. While best crops are obtained on well-drained, rich clay loams, crops can be grown on poor clays, sandy loams and peaty soils. Abundance of organic matter is necessary to hold moisture. Light, warm soils that heat up easily and lose moisture rapidly are undesirable. When oats follow corn, the soil is often only harrowed; but plowing is necessary for compact soils. On light, dry soils, rolling may be needed, followed by light cultivation. In order to get the crop in as early as possible in spring, fall plowing is desirable. The soil should be in good tilth, whatever method is used in preparing it.

(3) *Fertilizers.*—When the oat crop is fed heavily, especially with nitrogen, the growth of straw is excessive, and the yield of grain is less and of inferior quality. When oats follow corn on rich soil which has been liberally treated with farm manure or green-crop manure, generally no fertilizer is applied, especially if any has been used for the corn crop along with farm manure or green manure. Ordinarily, it may be well to apply at the time of seeding 200 or 300 pounds of **Mixture No. 5** (p. 577) especially when timothy and clover are seeded with it. On poor soils, deficient in organic matter, 8 to 10 tons of farm manure can be used per acre, or 250 to 500 pounds of **Mixture No. 6** (p. 578).

(4) *Seeding.*—In the North, seed is sown as early in the spring as possible. The amount of seed sown is usually

2 to 3 bushels. It is ordinarily covered 1 to 2 inches deep.

In the South oats are sown in the fall and extensively grown as a winter crop, for which they are especially valuable, serving as a cover-crop to prevent soil washing, and furnishing grain and green forage. When thus grown, top-dressing with about 100 pounds of sodium nitrate in spring is usually advised.

Oats as green-forage crop.—The oat crop is well adapted for use as green forage and for hay. For this purpose, rich loams well supplied with organic matter give best yields. When grown for green forage, the oat crop should be liberally fertilized, more nitrogen being used than for grain. An application of 250 to 500 pounds of **Mixture No. 7** (p. 580), can be used per acre. The crop is best for green forage when the oat grain is in milk-stage. In cool, moist seasons, the oat crop furnishes a continuous supply of green forage when one makes a series of sowings about 2 weeks apart.

Oats and peas as green-forage crop.—Oats and Canada field peas grown together make a very satisfactory green-forage crop, as well as being useful for hay, if desired. The soil is prepared so as to be fine and mellow to a considerable depth. Applications of plant-food may be used in the form of farm manure, 8 to 10 tons an acre, or 200 to 400 pounds **Mixture No. 2** (p. 543). The soil needs an abundance of organic matter and calcium carbonate. The amount of seed to use varies from 1 to 2 bushels of each per acre, but a great variety of proportions is used, according to individual conditions and preferences. The seed should be put in as early as possible in spring, being uniformly distributed. The best time for use as forage, is when the oat-grain is in the milk stage and the peas are forming pods. When made into hay, it is cut at the same stage.

Barley possesses several marked characteristics that

distinguish it in certain ways from other cereal crops. It grows under a wide range of climatic conditions; it can grow with a smaller supply of moisture than any other cereal. Though best adapted to a warm, dry climate, it grows well under other conditions. Barley is grown for grain, as green forage, pasturage and nurse-crop for alfalfa, clovers and grasses. It is used as a grain for two chief purposes, as a cattle food and for malting purposes in connection with the manufacture of malted beverages. When used for malting, the grain should have a high percentage of starch and a low amount of nitrogen compounds; the grains should be uniform in ripeness, size and variety, conditions that are essential to the requisite ability to germinate completely, evenly and quickly. For malting purposes, the grain must not be discolored, which is controlled largely by harvesting before ripening has gone too far. Barley crops are more easily injured by dew, rain or sunshine than other cereals.

Root systems of barley and oats. KANSAS STATION.

(1) *Crop-rotations for barley.*—Barley crops cannot be maintained continuously on the same soil as well as other cereals, and care is required to grow it in rotation. It often replaces wheat or oats. The following illustrate common rotations:

(a) Three to four years: Corn, 1 year; barley, 1 year; oats, 1 year, or timothy and clover, 1 to 2 years.

(b) Four to five years: Corn, 1 year; barley, 1 year; wheat, 1 year; clover or clover and timothy, 1 to 2 years.

(2) *Soil and preparation.*—Barley is more sensitive to

the character of soil than are other cereals. Sandy, well-drained soils are better than heavy clays or soils not well-drained. A fertile soil, not supplied with an excess of easily available nitrogen, is best, especially for malting barley. It is more important than for other cereals that the seed-bed be mellow and deep, in order to permit rapid root growth and to make available the plant-food supply in the upper layer of soil.

(3) *Fertilizers.*—The general use of fertilizers, as given in connection with wheat (p. 582), applies to barley. It is best to apply farm-manure to a corn crop preceding barley and, if more plant-food is needed, to apply the plant-food mixture as directed above. The short period of growth and limited range of the root system require that the plant-food should be in readily available condition. When grown for feeding purposes, larger amounts of nitrogen can be used; but when grown for malting purposes, less nitrogen and more potassium can be supplied in order to promote the production of starch. Experiments indicate that when materials which change insoluble into soluble potassium compounds are applied to a soil rich in potassium the barley crop is beneficially affected. Favorable results following the application of 300 to 400 pounds of salt per acre may be explained in this way. An abundance of calcium carbonate in the soil has a beneficial effect, in part, for the same reason.

(4) *Seeding.*—The grain should be put in generally between the time of sowing spring wheat and oats in the North. The amount of seed most commonly used varies from 2 to 2½ bushels.

Barley as a green-forage crop.—In many of the northern states, barley makes an excellent late-fall forage crop. The conditions required to grow oats as a forage crop apply to barley. It is sown about the middle of August, 2 to 2½ bushels of seed being used. The growth may also be used as a late fall pasture. In the South, barley

is sown in September or October and used as fall and spring pasture or as winter pasture. Good grain crops may be obtained even after considerable pasturage.

Barley and peas as green-forage crop.—Barley grown in combination with Canada field peas furnishes excellent late forage. About 1½ bushels of each are used for seed-

FERTILIZER EXPERIMENTS WITH BUCKWHEAT

Fertilized and unfertilized crops. This crop responds well to applications of fertilizers. WEST VIRGINIA STATION.

ing during the first half of August, other conditions being observed as in case of oats and peas (p. 589).

Barley as a nurse-crop.—Barley has been found extremely useful as a nurse-crop in starting seedings of alfalfa, clovers and grasses. It possesses several advantages for this purpose: (1) It seldom lodges; (2) the stems are shorter and less leafy than in case of other cereals, thus admitting sunlight and air; (3) it uses smaller amounts of water than other cereals. When bar-

ley is used as a nurse-crop one sows from 3 to 4 pecks of seed per acre.

Buckwheat grows at higher altitudes than in case of any other cereal and more is grown in higher latitudes than in case of other cereals. Its season of growth, 8 to 10 weeks, is the shortest of the cereals. It does best in a cool, moist climate, its yield being seriously decreased by hot, dry weather. It is injured by frost. It is grown largely for the grain, but to some extent as a green-crop manure.

(1) *Crop-rotations for buckwheat.*—Ordinarily no special rotation is observed in growing buckwheat, because it is commonly grown on the least valuable land, or for the purpose of taking the place of some other crop that has failed. Buckwheat leaves the soil in very mellow condition and for this reason is often followed by potatoes. The following rotation is adapted to the growing of buckwheat:

First year, clover, the first growth being cut and then plowed for buckwheat; second year, potatoes; third year, oats or wheat seeded with clover.

(2) *Soil and preparation.*—Buckwheat does best on somewhat sandy, well-drained land, but can be grown on heavy clays and even wet soils, though not to good advantage. The crop can mature on very poor soils, and it is therefore often relegated to the poorest and worst-tilled portions of a farm. Buckwheat will respond profitably to better treatment. For good crops, the land should be plowed and treated as for other cereals; early and thorough preparation will be repaid. This is, of course, not practicable when the crop is put in to take the place of some other crop that has failed.

(3) *Fertilizers.*—Buckwheat lodges badly on soils that are richly supplied with nitrogen. It responds well to applications of phosphorus and potassium. Since its growth occurs mostly during July and August, when

nitrification is taking place most rapidly, little or no nitrogen need be supplied on soils containing fair amounts of organic matter. On light, poor soils, deficient in organic matter, 4 to 6 tons of farm manure can be used; but, in general, farm manure is best applied to some preceding crop. On ordinary soils an application of 200 to 300 pounds per acre of **Mixture No. 5** or **No. 6** (pp. 577-578) should prove beneficial. When buckwheat follows clover, a mixture consisting of 200 pounds per acre of acid phosphate and 50 pounds of potassium chloride is suggested.

(4) *Seeding.*—The usual time of seeding is July 15 to August 15, though it may be put in any time from May to August. The amount of seed used varies from 2 to 5 pecks; it is covered 2 to 3 inches deep.

Buckwheat as a green-crop manure.—Buckwheat possesses some qualifications which fit it very well as a green-crop manure under some conditions. It grows rapidly, takes up considerable amounts of plant-food materials from the soil and, when plowed under, decomposes easily. If desired, two crops can be grown in one season. It cannot, however, like leguminous crops, make use of atmospheric nitrogen and, therefore, returns no more plant-food than it takes from the soil. Its special use as a green-crop manure is on soils too poor to raise any other crop; it is often useful in furnishing organic matter to poor, sandy soils where clover fails to grow. It also serves well as a cover-crop on soils that would otherwise lie bare during the latter part of the season after July. When used as a green-crop manure, it is preferably plowed under about the time it begins to blossom.

Millet is used in this country most largely as a green-forage crop, but to some extent as hay and as a cover-crop. It is adapted to hot weather, resisting drouth well. Under favorable conditions of moisture and warmth, the crop is ready to cut for forage in 6 to 10 weeks. It is easily killed by frost. It has been found useful as a crop

to put on new lands and also as a means of overcoming weeds, especially during hot weather.

(1) *Soil and preparation.*—Millet does best on rich, mellow, well-drained sandy loams. It can grow fairly on rather poor soils. On heavy clays or wet soils, it does not grow well. The soil should be given very careful preparation, much as for barley, the seed-bed being made mellow to a considerable depth in order to enable the shallow rootlets to range easily for food.

(2) *Fertilizers.*—Millet is distinctly a surface feeder. A good crop draws large amounts of plant-food from a rather limited layer of soil and often reduces the supply of available plant-food in this layer to such an extent as to affect the next crop unfavorably, unless heavily fed. When obtainable, 10 to 12 tons of well-decomposed farm manure should be worked into the soil after plowing. When commercial fertilizers are depended upon wholly, an application per acre can be made of 250 to 500 pounds of **Mixture No. 5** or **No. 6** (pp. 577-578).

Root system of sorghum, 75 days after planting. KANSAS STATION.

(3) *Seeding.*—Owing to the sensitiveness of millet to cold, seeding should be delayed until danger of frost is passed. This will ordinarily be after May 15 in the North; from then on until July will be a favorable time for seeding. The amount of seed used varies commonly from 2 to 4 pecks.

Millet as a cover-crop.—Millet can be put in as a cover-crop after rye or other early ripening crop, or when the hay crop fails. It can be started when it is too late to grow corn.

Sorghum grows wherever corn grows; but it does better on poor soils and with much less moisture than corn. The sweet varieties are used largely as forage in dry regions and it is grown also to some extent for the purpose of making sugar and syrup. In nearly all respects the raising of sorghum for forage is essentially the same as that of corn for the same purpose. Sorghum needs more attention in relation to weeds than corn, since its early growth is very slow. For this reason, it is well to have it follow a cultivated crop. For forage, the seed can be sown broadcast, using 20 to 25 pounds an acre, or seeded in rows at the rate of 10 to 12 pounds an acre. The crop should be liberally fed, using 6 to 8 tons of well-decomposed farm manure per acre, well worked into the soil and 200 to 300 pounds of **Mixture No. 5** (p. 577).

When sorghum is grown for sugar or syrup, 400 to 600 pounds of **Mixture No. 5** can be applied.

TABLE 59—APPROXIMATE AMOUNTS OF PLANT-FOOD CONSTITUENTS IN ONE CROP

Crop	Portion of crop	Yield per acre	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
			Lbs.	Lbs.	Lbs.
Corn......	Grain	25 bu.	23.2	9.1 (4. P)	5.5 (4.6K)
	Stalks, &c.	1500 lbs.	15.0	4.5 (2. P)	21.0 (17.4K)
	Cobs	250 "	1.0	0.2 (0.1P)	1.1 (0.9K)
			39.2	13.8 (6.1P)	27.6 (22.9K)
	Green forage	20000 lbs.	60.0	26.0 (11.4P)	66.0 (55. K)
Wheat	Grain	25 bu.	30.0	12.8 (5.6P)	6.0 (5. K)
	Straw	2500 lbs.	12.5	3.8 (1.7P)	15.0 (12.5K)
			42.5	16.6 (7.3P)	21.0 (17.5K)
Rye	Grain	20 bu.	19.1	9.8 (4.3P)	6.7 (5.6K)
	Straw	2000 lbs.	10.0	6.0 (2.6P)	17.0 (14.1K)
			29.1	15.8 (6.9P)	23.7 (19.7K)
	Green forage	15000 lbs.	67.5	30.0 (13.2P)	97.5 (81. K)
Oats......	Grain	25 bu.	16.0	6.[illegible] (2.9P)	4.[illegible] (4. K)
	Straw	1250 lbs.	8.0	2.[illegible] (1.1P)	15.6 (13. K)
			24.0	9.0 (4. P)	20.4 (17. K)
	Green forage	12000 lbs.	72.0	18.0 (8. P)	54.0 (4[illegible].8K)
Barley.....	Grain	25 bu.	21.0	9.0 (4. P)	6.0 (5. K)
	Straw	1600 lbs.	9.6	3.2 (1.4P)	17.6 (14.6K)
			30.6	12.2 (5.4P)	23.6 (19.6K)
	Green forage	10000 lbs.	40.0	15.0 (6.6P)	50.0 (41.5K)
Buckwheat	Grain	20 bu.	15.0	6.0 (2.6P)	3.0 (2.5K)
	Straw	5000 lbs.	62.5	7.5 (3.3P)	57.5 (47.7K)
			77.5	13.5 (5.9P)	60.5 (50.2K)
	Green crop	10000 lbs.	40.0	8. (3.5P)	35.0 ([illegible]. K)
Millet	Green forage	20000 lbs.	60.0	20.0 (8.8P)	100.0 (83. K)
Sorghum ..	Green forage	20000 lbs.	60.0	24.0 (10.6P)	60.0 (49.8K)

P, phosphorus. K, potassium.

CHAPTER XXXI

TUBER AND ROOT CROPS

The crops to be considered in this chapter are the following: (1) Potatoes, (2) sweet potatoes, (3) beets, (4) turnips, (5) carrots, (6) parsnips, (7) radishes, (8) salsify.

These crops are used largely as human food, but to some extent as food for farm animals. They possess certain characteristics in common which distinguish them from cereals, especially in their relations to plant-food. In the first place the character of root growth is such that these crops are not commonly regarded as strong feeders; that is, the root system of each plant does not range widely through the soil and, in consequence, the plant-food supply within reach is less than in case of plants whose roots have an extensive reach. A supply of readily available plant-food in the neighborhood of the growing roots, therefore, meets with prompt response. In most cases, it is desirable that the soil shall be mellow to a much greater depth than for cereals in order to permit the root to go down as deeply as possible in its reaching after food. In the second place, the food product that is most characteristic of these crops is carbohydrate material, especially starch and sugar. As already pointed out (p. 73), such crops use relatively large amounts of potassium. Many of the crops have a growing season of good length and can utilize organic nitrogen compounds. While the percentages of plant-food constituents are not large in these crops, the yields are heavy and therefore the amounts of plant-food contained in the crop grown on an acre are large in the aggregate as compared with many other crops.

Potatoes.—Though potatoes grow best in moderately moist, cool climates, they do well under a great variety of climatic conditions and are widely distributed.

(1) *Crop-rotations for potatoes.*—Crop-rotations are essential for best results with potatoes for several reasons, and especially because, when grown continuously on the same soil, they are subject to the scab and other diseases. They do especially well after clover or cowpeas. The following rotations are given as illustrations:

(a) Three years: Winter wheat seeded to clover in spring, 1 year; clover, hay and green-manure, 1 year; potatoes, 1 year.

FERTILIZER EXPERIMENTS WITH POTATOES

Comparison of potassium sulphate and chloride (muriate). Under the conditions of the experiment, sulphate gave 255 bushels per acre, and muriates, 204 bushels. MASSACHUSETTS STATION.

(b) Four years: Rye, seeded with clover and timothy, 1 year; hay, 1 year; potatoes, 1 year; oats or barley, 1 year.

(c) Four years: Wheat seeded with clover, 1 year; clover hay and green-crop manure, 1 year; potatoes, 1 year; beans, 1 year.

In case of long seasons, potatoes often follow some early crop, or are put in as an early crop and followed by something else.

(2) *Soil and preparation.*—While potatoes do well on many kinds of soil, they do best on rich, well-drained, sandy loams containing an abundance of organic matter. When grown on heavy soils not well drained, the tendency is for the production of excessively watery tubers of undesirable quality. The soil should be mellow, deep and porous. It is desirable that heavy soils be plowed in the fall. Deep plowing is advisable, since the roots feed well down in the soil if they are given a chance.

(3) *Fertilizers.*—In discussing the use of fertilizers for potato crops, we must take into consideration (a) the amount of organic matter in the soil, (b) the time of season during which the crop is grown, (c) the quality of the crop, (d) the time and manner of application, and (e) the amount of plant-food constituents to use

Roots of potato plant (after Coburn).

(a) Amount of organic matter in soil. In soils already containing an abundance of organic matter, whether furnished by farm or green-crop manure, only application of commercial plant-food constituents needs to be considered. However, in soils not well supplied, organic matter is furnished by farm manure or green-crop manure, preferably leguminous, according to the special conditions on each farm. When farm manure is available and is not preferred for some other crop, it is applied at the rate of 10 to 12 tons an acre; if fresh and coarse, it is better to apply it in the fall and plow in, but, if well-decomposed, it can be applied in the spring to the plowed ground and thoroughly harrowed in. When farm manure is used in larger amounts, it is regarded as better practice to apply it to corn or clover or grass and then follow

with the potato crop, since the direct application of farm manure favors the growth of scab on tubers.

(b) Early and late potato crops. Early potatoes require liberal amounts of plant-food and respond well in yield even on fertile soils to generous applications of available plant-food constituents. It must be kept in mind that the growing season of the early crop is desired to be short, and much of the growth therefore comes before nitrification and other processes that make the soil's plant-food available have reached their most extensive activity and produced their greatest effects. Therefore, the forms of plant-food applied should be those readily available. In the case of late potatoes, the growing period is more prolonged and comes during the portion of the season when the unavailable plant-food in the soil is being most rapidly converted into available condition. Therefore, those forms of plant-food constituents, especially nitrogen, can be used which become available gradually; for example, in the case of early potatoes, the nitrogen applied is preferably in the form of nitrate for the most part, while, in the case of late potatoes, it may be distributed in the forms of nitrate, ammonia and organic nitrogen, such as sodium nitrate, ammonium sulphate, tankage, dried blood, or cottonseed-meal or fish-scrap, etc.

(c) The quality of the crop. There has been some experimental work done in relation to the much-discussed point as to the effect of potassium sulphate, as compared with the chloride, on the quality of potato tubers. In respect to yield, results may not vary much, whichever compound is used; but experiments show that in some cases sulphate gives larger yields. So far as present knowledge goes, the use of potassium chloride, especially on clay soils, appears to favor a larger percentage of water in the potatoes than when sulphate is applied. On lighter soils, there appears to be little or no appreciable difference. It is said, however, that the use of sulphate produces tubers of cleaner appearance and more uniform size. On heavy or moist soils, it is, therefore, well to take the precaution of using the sulphate.

(d) Time and manner of application. When large amounts of commercial fertilizers are used for potatoes, there is serious danger of injuring the seed, especially if all the fertilizer is put in the row at the time of planting. In the writer's experience, applications of over 1,000 pounds an acre are very apt to work injury in this way. The best method, on the whole, of applying large amounts is to distribute broadcast one-half, or two-thirds in case of very large amounts, and work this into the soil thoroughly before planting and then, at the time of planting, put the rest in the row. Under ordinary conditions, it is suggested that not over 500 pounds per acre be put in the row unless it is kept from direct contact with the seed-potatoes. Some growers put one-half in the row at planting and one-half as a top-dressing along the rows when the plants are 2 to 4 inches high, using special machinery for applying and covering.

(e) The amount of plant-food constituents to use. The general rule among potato growers, especially on light soils, has been to make large applications of high-grade fertilizers, for example, from 1,000 to 2,000 pounds per acre of a fertilizer containing 4 per cent. of nitrogen, 8 of available phosphoric acid (3.5 P) and 10 of potash (8.3 K), equal to 40 to 80 pounds of nitrogen, 80 to 160 pounds of available phosphoric acid (35 to 70 P) and 100 to 200 pounds of potash (83 to 165 K). Experiments on light loam indicate that applications above 1,000 pounds an acre are less economical than 1,000 pounds or less. While larger yields are usually secured with 1,500 pounds, the increased yield is not, in general, enough to pay for the fertilizer used above 1,000 pounds; and beyond this, the larger the amount of fertilizer used, the smaller becomes the profit per acre. Of course, there may be conditions which justify the larger amounts, but before applying over 1,000 pounds an acre to whole crops, it is well to experiment with limited areas. It has

also been found that, except on soils deficient in potash, less than 100 pounds of potash an acre will suffice.

Plant-food mixture No. 8.—*For early potatoes and garden crops.*

Sodium nitrate	250 lbs.	(38 lbs. nitrogen)	
Ammonium sulphate	100 "	20 " "	
Tankage (6.5N—9P_2O_5)	350 "	22 " "	and 32 lbs. phosphoric acid, or 14 lbs. P)
Acid phosphate	900 "	(126 " available phosphoric acid or, 55 lbs. P)	
Potassium sulphate or chloride	400 "	(200 " potash, or 165 lbs. K)	

This mixture contains about 4 per cent. of nitrogen, 8 of phosphoric acid (3.5 P), mostly soluble, and 10 of potash (8.3 K). The availability of the nitrogen is such that it is ready for use, part at once and all of it during the growth of the crop.

On soils in good condition, it should be used at the rate of 500 to 1,000 pounds an acre, furnishing the following amounts of plant-food:

Nitrogen	Nitrate	10 to 20 lbs.	
	Ammonia	5 to 10 "	
	Organic	5 to 10 "	
Total phosphoric acid		40 to 80 "	(18 to 36 lbs. P)
Available phosphoric acid		32 to 64 "	(14 to 28 " P)
Potash		50 to 100 "	(42 to 84 " K)

Plant-food mixture No. 9.—*For late potatoes and general garden crops.*

Sodium nitrate	125 lbs.	(20 lbs. nitrogen)	
Ammonium sulphate	100 "	20 " "	
Tankage (6.5N—9P_2O_5)	600 "	40 " "	and 54 lbs. phos. acid, or 24 lbs. P)
Acid phosphate	775 "	(109 " "	available phos. acid, or 48 lbs. P)
Potassium sulphate or chloride	400 "	(200 " "	potash, or 165 lbs. K)

On soils in good condition, Mixture No. 9 can be used in amounts from 500 or 600 pounds up to 1,000 pounds an acre. The nitrogen is distributed in such forms that only one-fourth is immediately available, the other forms becoming available during the growth of the crop.

On soils known from experience to contain considerable amounts of potassium compounds, which have been kept well supplied with organic matter by use of clover or other

leguminous crops, the amount of potassium compounds can be reduced one-half. This is easily done in case of mixtures 8 and 9 in the following manner: Use the same amounts of materials furnishing nitrogen and phosphorus, but only 200 pounds of potassium sulphate or chloride, and then add 200 pounds of drier (p. 480). The resulting mixture contains 4 per cent. of nitrogen, 8 of phosphoric acid (3.5 P) and 5 of potash (4 K).

It should be added in this connection that the soil should not be limed for a potato crop, especially with slaked-lime (calcium hydroxide) or quicklime (calcium oxide), owing to the tendency to produce scab. The application is best made for the leguminous crop in the rotation.

Sweet potatoes.—In growing this crop, certain qualities of the product must be taken into consideration. Watery sweet potatoes are undesirable; those of good edible quality should be mealy when cooked. This quality is the result of soil conditions and of plant-food supply. From the market standpoint, potatoes of medium size and well-rounded shape are preferable to those of large size or elongated shape. The crop is one not grown on a commercial scale north of New Jersey in the eastern United States. The best climatic conditions are warmth and moisture during most of the growth, followed by moderately dry weather during the final maturing.

(1) *Crop-rotations for sweet potatoes.*—An excellent preparation for a sweet-potato crop is the growth of some crop like corn, tomatoes, melons, etc., with which crimson clover is seeded at the last cultivation and then plowed under when 6 to 8 inches high. Crimson clover can also follow any early crop for the same purpose.

(2) *Soil and preparation.*—Soils best adapted for sweet potatoes are well-drained, porous, warm and sandy. Good drainage is very essential. Some clays that are of highly crumbly structure and porous are successfully used. The land is plowed rather shallow, usually 5 or 6 inches, and at

a time in spring when it crumbles perfectly under the plow and gives a fine tilth under the harrow. Special care is required to pulverize the soil very completely in case of sandy soils containing enough clay to form clods by baking.

(3) *Fertilizers.*—The use of leguminous crops to furnish organic matter, with some nitrogen and the application of commercial fertilizers, in addition, are generally advocated as more economical than the use of farm manure. Large applications of nitrogen, particularly as nitrate, are to be avoided, since quality is impaired, though the yield is increased. Larger proportions of potassium in relation to nitrogen and phosphorus are generally used.

In the South liberal applications of the following mixture have been successfully used per acre:

Cottonseed-meal......	360 lbs.	(containing about	25 lbs.	of	nitrogen).
Acid phosphate.......	320 "	(" "	45	"	available phos. acid)
Kainite.............	640 "	(" "	80	"	potash).

This mixture contains about 2 per cent. of nitrogen, 3.5 per cent. of phosphoric acid and 6 per cent. of potash. or, figured on the basis of 4 per cent. of nitrogen, the phosphoric acid would be about 7 per cent. and the potash 12.

In New Jersey, a similar formula is used, except that the amount of nitrogen is smaller in proportion to phosphorus and potassium, the New Jersey formula containing 3 per cent. of nitrogen with 7 of phosphoric acid and 12 of potash, and in some cases additional amounts of phosphorus and potassium are used, which increase the percentage of phosphoric acid to 8 or 9 per cent. and the potash to 12 or 15 per cent., reducing the nitrogen relatively to 2 per cent. For a fertilizer containing 3 per cent. of nitrogen, 7.5 of phosphoric acid and 12 of potash, the following materials can be used:

Sodium nitrate...........	100	pounds	(15	pounds	nitrogen)
Ammonium sulphate.......	50	"	(10	"	")
Dried blood..............	350	"	(35	"	")
Acid phosphate...........	1025	"	(150	"	phosphoric acid)
Potassium chloride........	475	"	(240	"	potash)

Ground fish, cottonseed-meal or meat-tankage can be substituted for dried blood; the main purpose is to have

only a small part of the nitrogen immediately available. The amounts of fertilizing mixtures applied vary from 600 pounds per acre up.

It is customary to apply the fertilizer and work it into the soil two or three weeks before setting the plants. especially on light soils, or when kainite is used. When large amounts, 1,200 pounds or more per acre, are used, about two-thirds may be applied in this way and the remainder in the furrows a week or so before setting plants.

Beets are grown for three general purposes, as a garden crop for table use, as a field crop for cattle-food, and as a commercial source of sugar. Different varieties are adapted to the particular purpose for which the crop is grown. Beets do best in cool climates with a large amount of sunshine, especially during the maturing period in case of beets grown for sugar.

(1) *Crop-rotations for beets.*—Beets do well after such crops as corn, cabbage, wheat, etc., and also after clover. For field-beets or sugar-beets, the following rotations serve as good illustrations:

(a) Four years: Corn, with heavy application of farm manure, 1 year; beets, 1 year; oats or barley seeded with clover, 1 year; clover, 1 year.

(b) Five years: Wheat, 1 year; beets, 1 year; clover, one crop for hay and one for green manure, 1 year; potatoes, 1 year.

(2) *Soil and preparation.*—Beets grow well on a variety of soils, but whatever the general character, it should be well-drained, deep and mellow. Generally speaking, beets grow well on any soil good for wheat, corn or potatoes. For best results in yield, rich clay loams are best. A fairly level soil is desirable, especially for sugar-beets. Lighter soils mature the crop earlier, which is a marked advantage in case of early beets for table use. It is generally desirable to plow in the fall. especially for early table-beets and in case of soils at all heavy. The plowing should be deep to permit exten-

sion of feeding roots downward. For sugar-beets and mangels, plowing should be 9 inches deep, followed by a subsoiler loosening the soil 6 or 7 inches more. As early in spring as conditions permit, the soil is put into fine tilth and made mellow just before planting, for whatever purpose beets are grown.

(3) *Fertilizers.*—The treatment with fertilizers varies materially according to the end in view. When farm manure is obtainable, it gives excellent results, if properly used and supplemented with commercial fertilizer. When heavy applications of coarse manure are made, it is better to apply to a crop preceding or to plow in during the fall preceding the beet crop. On rather heavy soils, as much as 20 tons or more an acre of partly decomposed farm manure can be applied just before planting with satisfactory results, even on sugar-beets, but such treatment cannot be regarded as economical under most conditions. When farm manure is used, an application of not more than 10 or 12 tons is advised under ordinary circumstances. The use of commercial fertilizers we will take up in connection with each of the special uses for which the crop is grown.

Root system of sugar-beet. CALIFORNIA STATION.

(a) Fertilizers for early garden-beets. In growing early beets for market, the chief aim is to push the growth as rapidly as possible and get them into market when prices are highest. Success in accomplishing this depends, other conditions being favorable, upon a liberal supply of available nitrogen and phosphorus. The early growth takes

place when soil nitrates are usually at their lowest and before their formation has been actively renewed in spring. Therefore, a generous supply of nitrate is desirable. At the time of planting, there should be a good supply of available nitrogen, phosphorus and potassium within reach of the young plants; however, it is better not to apply at planting time all the nitrate to be used, but to reserve some for several top-dressings; because, if it were all applied in the soil at the start, there would be risk of considerable loss of nitrate by leaching (p. 179) in case of considerable rainfall, which is common at the season when the beet crop is getting started. An application of 800 to 1,200 pounds of **Mixture No. 8** (p. 603) at the time of planting is suggested. After the plants are well started, there should be surface applications of 50 to 100 pounds of nitrate (p. 532) about once in ten days for three or four weeks. When earliness is not an object, the top-dressings can be smaller or omitted altogether. On lighter soils, the first application may be larger than the one given above.

(b) Fertilizers for beets grown as cattle-food. In growing beets for this purpose, the chief object is to obtain a large yield, which depends on rapid and uninterrupted growth. The season of growth is prolonged and it is therefore not necessary to supply the nitrogen so largely in the form of nitrate as in the case of early table-beets. Mangels or mangel wurzels, known also as mangolds, field-beets and cattle-beets, are very extensively grown for cattle-food. Sugar-beets are also grown for the same purpose. Whichever kind is used, the plant-food requirements are the same. Farm manure can be used to advantage, applying 10 to 12 tons, and an application of 500 pounds of **Mixture No. 9** (p. 603) can be worked into the soil just at seeding. On light soils, on which no farm manure is used, 800 to 1,000 pounds of **Mixture No. 8** or No. 9 can be used. Or, if preferred, the following mixture can be used:

Plant-food mixture No. 10.—*For use on field-roots.*

Sodium nitrate	200 lbs.	(30 lbs. nitrogen)
Ammonium sulphate ..	50 "	(10 " ")
Tankage (6.5N—9P_2O_5)	300 "	(20 " " and 27 lbs. phosphoric acid, or 12P)
Acid phosphate	950 "	(133 " available phosphoric acid, or 60 lbs. P)
Potassium chloride	280 "	(140 " potash, or 116 lbs K)
Drier	220 "	

This mixture contains about 3 per cent. of nitrogen, 8 of phosphoric acid (3.5 P), mostly soluble, and 7 of potash (5.8 K). The availability of the nitrogen is such that it is ready for use, about one-half at once, and the remainder during the growing season. The following mixture can be used for lighter soils when nitrate is in danger of loss by leaching and when bacterial action is sufficient.

Plant-food mixture No. 10 A.

Sodium nitrate........	100 lbs.	(15 lbs. nitrogen
Ammonium sulphate...	75 "	(15 " ")
Tankage(6.5N—9P_2O_5)	500 "	(30 " " and 45 lbs. phosphoric acid, or 20P)
Acid phosphate	825 "	(115 " available phosphoric acid, or 50 lbs.P)
Potassium chloride....	280 "	(140 " potash, or 116K)
Drier	220 "	

(c) Fertilizers for sugar-beets. Sugar-beets, when grown for production of sugar, are valued according to richness and purity of sugar in the beets and for the yield of beets per acre; that is, for the yield of sugar per acre. Excessive application of nitrogen produces increased yields of beets, large in size, but with decreased capacity for sugar production; enough nitrogen, however, must be used to promote rapid growth early in the season. In the production of sugar, potassium is highly important and on light soils must be supplied in liberal amounts. Well-decomposed farm manure well worked into the soil before seeding has given excellent results, especially on soils inclined to be at all heavy. An abundant supply of quickly available phosphoric acid is essential for the purpose of promoting early, rapid growth. Phosphoric acid is applied in considerably larger amounts than analysis of the beet indicates. The formation of sugar occurs in the latter part of the growing season, and in order that this may not be too much delayed, it is important during the early stages of growth to encourage rapid and extensive

growth of leaves, since it is through the agency of the leaves that sugar is formed (p. 163). If slow-acting forms of nitrogen are supplied, the vegetative growth is prolonged unduly and the process of sugar formation is retarded, so that the amount formed is apt to be less than where it begins earlier.

For the foregoing reasons, plant-food should be supplied in readily available forms and in generous amounts. These requirements are met by **Mixture No. 8** (p. 603), of which an application of 600 to 1,000 pounds an acre will not usually be found excessive on good soils; while on light soils the amount may be 900 to 1,200 pounds.

The plant-food in the fertilizer will be more economically used if it is applied in three portions, one-half being thoroughly worked into the soil immediately before seeding, one-fourth after the plants are up and just before the first cultivation, and the remainder just before the second cultivation. When applied in this way, the danger of loss of nitrate by leaching in case of heavy rainfall is diminished, the soluble phosphate has chance to reach the plant roots before becoming entirely reverted, and the direct action will be apt to be more manifest than when all the plant-food is applied at the time of seeding or before.

(4) *Seeding.*—Beet seeds are sown in rows, the distance between rows varying according to the special purpose in view; in case of garden-beets, the rows may be only 12 inches apart, though usually far enough to permit use of horse-cultivator; in case of ordinary field-beets and sugar-beets, the rows are 18 to 24 inches apart, while with mangels the distance may be 2 to 3 feet. The seeds are covered to a depth varying from ½ to 1½ inches. The amount of seed used varies usually from 5 to 8 pounds an acre for field-beets, but from 15 to 20 pounds for sugar-beets. It is preferable to use too much seed than to have the plants too thinly scattered in the row. When the plants are high enough to handle easily, they are thinned. In case of garden-beets, this is usually done when the tops are large enough to use as

greens and, in case of field and sugar-beets, when four leaves show. Garden-beets are thinned so as to leave 6 inches between plants; ordinary field-beets and sugar-beets are about 8 inches apart, while mangels are 8 to 10 inches.

(5) *Cultivation.*—For whatever purpose grown, beets should be kept as thoroughly cultivated as conditions permit, as often as once in 7 to 10 days if possible. The early cultivation should be fairly deep in order to remove weeds and to enable the soil to receive and hold moisture to best advantage.

Turnips are grown for table use and to some extent for feeding sheep and cattle; they may also be utilized at the same time as a cover-crop. As a garden crop, turnips are grown for early market as well as for ordinary market purposes. Turnips ordinarily require a damp, cool climate; they need less sunshine than beets, especially sugar-beets. Rutabagas bear about the same relation to ordinary turnips that mangels do to beets. They are grown largely for stock-feeding. In respect to place in crop-rotations, character of soil, preparation and cultivation, the statements made regarding beets apply to turnips when grown under usual garden and field conditions. The general conditions of seeding are about the same as with beets, except that the amount of seed used is only 2 to 4 pounds an acre.

Fertilizers.—It has been shown that turnips respond most favorably to a generous supply of soluble phosphorus compounds. When soil have been treated with 10 tons of good farm manure per acre, the application of phosphoric acid alone in soluble form usually is sufficient to secure good crops, especially on soils not deficient in potash. For the growing of early turnips for table use, the same method of treatment with fertilizers is recommended as with early beets (p. 607). For field-turnips grown with farm manure on good soils, an application of 250 pounds of acid phosphate and 75 pounds of potassium chloride may be used, or 500 pounds of **Mixture No. 10** or **10 A** (p. 609); on light soils, larger amounts should be applied.

Turnips grown as cover-crops may be used afte- any early crop or may be seeded in corn at the time of the last cultivation. They are then available for late fall and winter feeding. Some deep-rooting variety is preferable for use as cover-crop. The seed is sown broadcast at the rate of 2 or 3 pounds an acre.

Carrots are grown for both table use and food for farm animals. The crop is hardy, being adapted to quite wide climatic and soil variations. The methods of treatment employed in growing beets and turnips are applicable to carrots. The soil should be deep and well supplied with plant-food, a rich, mellow loam being most suitable. Since the early growth is very slow, it is desirable to seed the crop on soil as free as possible from weeds. Fertilizers are used as in case of field crops of beets and turnips.

'Parsnip in mellow soil; (*b*) compact soil. All root crops need a deep, mellow soil for best growth. IDAHO STATION.

Parsnips are largely grown as a garden crop. They grow well on rather heavy loams and even on clay soils. Since the roots grow long, it is important that the soil be well loosened to the depth of 16 or 18 inches. The cultural conditions that apply to beets and turnips are suited to parsnips. Excessive supply of nitrogen is undesirable as tending to produce a coarse texture. The amount of seed used per acre varies from 4 to 6 pounds, but, if more than a year old, it is apt not to grow. For table use, the roots are best left in the ground over winter, or stored in a cool place, since they acquire a sweetness and tenderness that they do not posess in the fall.

Radishes are grown both as a garden crop and as a greenhouse crop. They are hardy and among the most rapid-growing and earliest garden crops. In order to be tender and crisp in quality, they must be raised under conditions

which permit continuous, rapid growth. They are especially adapted to cool weather; when grown in hot weather, they tend to develop a rank growth, which results in a tough, fibrous or stringy texture, lacking in desired crispness and tenderness. The soil should be mellow, well supplied with organic matter and an abundance of easily available plant-food. For a fertilizer, **Mixture No. 8** (p. 603) is adapted to the needs of radishes, applying 500 pounds or more per acre and working it lightly into the soil just before or at the time of seeding.

Salsify or vegetable oyster is a plant resembling the parsnip somewhat in its root growth, except that salsify roots are not as large. When cooked, the roots have a flavor resembling that of oysters. It is grown only for table use. It is slow of growth, requiring the entire season. It is best adapted to deep, rich, moist soils. It is planted in rows 12 inches or more apart, and the plants after thinning stand 4 to 5 inches apart in the row. The amount of seed used per acre is 8 to 10 pounds. The culture and general treatment are essentially the same as for other root crops. The roots are better for cooking when left in the ground through winter. **Mixture No. 9** (p. 603) is adapted to the needs of this crop in amounts of 500 pounds or more per acre.

TABLE 60—APPROXIMATE AMOUNTS OF PLANT-FOOD CONSTITUENTS IN ONE CROP

Crop	Yield per acre	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
		Pounds	Pounds	Pounds
Potatoes, Irish....	150 bu.	31.5	13.5 (6. P)	45.0 (37. K)
" sweet...	200 bu.	27.5	11.0 (4.8P)	55.0 (45.7K)
Beets, common ...	25,000 lbs.	62.5	25.0 (11. P)	125.0 (104. K)
" mangels....	40,000 "	60.0	40.0 (17.6P)	140.0 (116. K)
Turnips, common .	20,000 "	50.0	20.0 (8.8P)	90.0 (74.7K)
" rutabagas	20,000 "	40.0	24.0 (10.5P)	100.0 (83. K)
Carrots.........	10,000 "	23.0	13.0 (5.7P)	53.0 (44. K)
Parsnips.	12,000 "	26.4	24.0 (10.5P)	78.0 (65. K)
Radishes.........	2,000 "	3.0	1.2 (0.5P)	7.0 (5.8K)
Salsify..........	5,000 "	25.0	8.0 (3.5P)	27.5 (22.8K)

P, phosphorus. K, potassium.

CHAPTER XXXII

GARDEN CROPS

The growing of garden crops on a commercial scale has become a very important agricultural specialty, particularly within conveniently located areas that supply large cities with vegetables. In market-garden regions, many crops are grown in succession on a relatively restricted area. There is no line of crop production in which so great dependence is placed upon the use of commercial fertilizers as in the case of garden crops grown for market. Not only is it sought to increase the yield, but especially to control the quality. Formerly, sole dependence was placed upon farm manure and composted materials to supplement the plant-food needs of soils, and this is still true in many cases, but market-garden farmers have come to depend increasingly upon commercial plant-food materials, which they use in amounts that would be extravagant for ordinary crops.

The term "truck-growing" is applied to the growing of vegetables at considerable distances from markets, as, for example, the growing of early vegetables in the South for northern markets. This is usually carried on with one or more crops for which local conditions of soil and climate are especially adapted. These crops are grown as part of a system of general farming, and not as exclusive crops. The same general requirements of soil and of plant-food apply as in the case of the same crops grown under ordinary market-garden conditions, but modified according to local environment. Truck-farming may be regarded simply as market-gardening on an extensive scale.

SOME GENERAL CHARACTERISTICS

While market-garden crops vary greatly in individual characteristics, they have certain conditions of growth and

certain properties in common. In general, their growth is stimulated or forced so as to make quick and continuous development. So far as preparation of soil and supply of plant-foods are concerned, the aim is to furnish such conditions that, with a proper amount of sunshine and rainfall, the crop will be pushed forward as speedily as possible without delay or interruption of continuous growth.

One edible quality which all vegetables must possess in common is that they be agreeable to the taste, appetizing, palatable; this is usually dependent on some peculiar taste or combination of taste and smell. For example, sweetness in peas, sweet corn, melons, etc., together with the additional flavor that is characteristic in each case, determines the palatability, while in rhubarb, tomatoes, etc., it is combination of acidity and other qualities; in the case of onions, horseradish, cabbage, turnips, etc., the characteristic flavor is due to the presence of certain sulphur compounds. Overdeveloped flavor, as in the case of excessive pungency found in some onions, or the strong disagreeable flavor of some celery, disagreeable bitterness in lettuce, over-acidity in tomatoes, absence of sweetness in peas, corn, etc., may, to some extent, be due to failure to regulate the supply of plant-food, although these defects are often due to the variety of plant used or to special weather conditions.

Another edible quality of importance in most vegetables is that dependent on tenderness, succulence and crispness. The development of tough, fibrous texture greatly depreciates this quality, as illustrated in case of beets, celery, lettuce, radishes, etc., of poor quality. This defect is more or less due to regulation of plant-food supply and can be prevented in large measure.

Generally speaking, the ideal qualities of vegetables are dependent upon conditions that make possible quick and uninterrupted growth. When growth is interrupted or retarded, then some undesirable quality of flavor or texture is likely to make its appearance. So far as interruption of

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(1) Breeding experiments with melons. The two varieties shown

on either side of the greenhouse are the parent forms of the cross on which studies of inheritance of character are being made.

(2) Parents and offspring in melon cross. Parents on either side; hybrid in middle. The hybrid possesses the straw-colored skin of melon No. 149, the netting of Sutton's Superlative and is intermediate in ribbing, size and shape.

(3) Cross-sections of melons, showing comparative size of cavities and thickness of flesh. Hybrid in center has very small cavity and is a great improvement on either parent. NEW HAMPSHIRE STATION.

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growth is due to lack of sunshine, or of rainfall, when this is the source of water supply, one is, of course, helpless. However, under favorable conditions of soil, of light, warmth and moisture, the quality of vegetables can be reasonably well controlled by judicious regulation of the amounts and kinds of plant-food supplied.

The problem of successfully growing market-garden crops becomes one, therefore, of so regulating the supply of plant-food as to insure rapid and continuous growth, weather conditions being favorable. In this connection, it may be stated that many market-gardeners in the East are making extensive use of irrigation, which eliminates the unfavorable factor of lack of rain.

SOIL CONDITIONS

For the successful growth of garden crops, there are certain essential soil conditions that are common to all market-garden soils. Under this head, we will briefly consider: (1) Organic matter, (2) calcium carbonate, (3) influence of character of soil, (4) preparation.

Organic matter.—Garden soils should contain a generous supply of organic matter. The customary method of keeping up the supply has been to make large applications of farm manure every year. The general tendency is in the direction of depending more upon the growth of some quick-growing leguminous cover-crop (crimson clover, cowpeas, etc.) as part of a well-planned crop-rotation. This

is easy of accomplishment where the growing seasons are long. The addition of nitrogen by leguminous crops is the most economical means of supply, as has been repeatedly emphasized.

Calcium compounds.—The necessity of keeping a large amount of decaying organic matter in a soil involves the formation of acids (p. 125) and the using up of the calcium carbonate. In order to prevent the exhaustion of calcium carbonate, which results in soil acidity, it is necessary to keep market-garden soils, in case of most crops, well supplied with this compound (p. 379).

Influence of character of soil.—While some vegetables grow on a great variety of soils, others are more limited. In general, the growth of individual crops is more or less localized, one or more crops being grown in one locality where the soil and climatic conditions have been shown to be especially favorable. In the case of home gardens, whatever kind of soil happens to be at hand is used, and this is adapted as far as possible to the growing of as great a variety of products as are used in the household. As regards the influence of the character of the soil upon the crop growth, light, porous, warm soils promote rapid growth and early ripening, while the reverse is true of heavy soils. Light soils should, therefore, be modified to hold moisture and heavy soils to become more open.

Preparation of soil.—All market-garden soils require very thorough tillage. The depth required varies for the different crops, but in all cases the soil must be mellow and finely pulverized.

USE OF FERTILIZERS

To promote early and rapid and continuous growth requires the presence of nitrate and soluble phosphates in considerable amounts. Though phosphorus is used by garden crops in much smaller amounts than either nitrogen or potassium, we must remember that its supply in most soils

is much less (p. 112). Potassium is used in relatively large amounts in the leafy portions of crops; therefore, when this portion of the crop is removed for market, the amount of potassium taken from the soil is usually greater than where some other portion of the plant is sold. Generally speaking, potassium needs usually to be applied rather generously on light, sandy soils and soils rich in muck or peat. On soils containing fair amounts of clay, much lighter applications

BREEDING EXPERIMENTS WITH SQUASHES. NEW HAMPSHIRE STATION

often suffice, especially if the soil is well supplied with calcium carbonate, and also when considerable amounts of sodium nitrate are used (p. 437).

The traditional method of maintaining plant-food supplies in garden soils has been use of large quantities of farm manure, 40 tons an acre or more being applied when obtainable, and, in extreme cases, as much as 80 to 100 tons. The application of 40 tons means about 400 pounds each of nitrogen and potash, and 200 pounds of phosphoric acid.

amounts which would be regarded as enormous if applied in the form of commercial plant-foods. The exclusive, long-continued use of farm manure is open to several objections: (1) Unless the soil is kept well occupied with growing plants, more or less nitrogen is in danger of being lost in drainage. (2) There is liability with large amounts of fresh manure of excess of nitrate in soil, which will produce too rank growth of stems and leaves at the expense of the edible portions in those crops which are grown for other parts than stems and leaves. (3) Trouble from plant diseases is promoted by excessive use of farm manure. Good farm manure can be advantageously used, but the applications should be moderate and supplemented by commercial plant-food, especially phosphorus.

The general rule is to apply enough of each plant-food constituent to meet or exceed the demands of large crops; the kinds and amounts vary in case of different crops. As a general fertilizer for market-garden use, **Mixtures No. 8** and **No. 9** (p. 603) or modifications of these have been extensively used with success.

These fertilizers can be used on practically all garden crops, adaptations being made in special cases by varying the amounts or by supplementing with additions of other materials.

We shall attempt to consider only those crops that are of more general interest and, for the sake of convenience, will divide them into groups, the members of which are alike in respect to their plant-food treatment. These are as follows: (1) Asparagus and rhubarb, (2) beans and peas, (3) cabbage, cauliflower and brussels sprouts, (4) celery, (5) cucumbers, muskmelons, watermelons, pumpkins and squashes, (6) sweet corn, (7) lettuce and spinach, (8) onions, (9) tomatoes, (10) eggplant.

Asparagus is, on account of its being one of the earliest spring vegetables, an important product for market and also a favorite crop for home gardens. It is very hardy and, if once properly established and cared for, the same roots

will continue to produce generous annual yields for 20 years or more. While other crops cannot be grown on the same land with asparagus, and while it is cropped only once, yet its cropping season is spread over one or two months and the yield can be made large by generous feeding and care.

(1) *Soil and preparation.*—Asparagus will grow on almost any kind of agricultural soil, but it does best on deep, well-drained, loose, rich loams. In preparing soil for a permanent planting of asparagus, the ground should be plowed 10 or 12 inches deep the fall before and then well harrowed in the spring.

(2) *Planting and cultivation.*—In planting a small bed for home use, time can be saved by purchasing two-year-old roots. In growing roots for one's own use, seed is sown early in spring in rows 14 to 16 inches apart at the rate of one ounce for 50 feet, furnishing about 400 plants; the seed-bed should be rich, mellow and loose. The soil is kept free from weeds and well cultivated during the season. The roots can be transplanted the spring following or left until the second spring before transplanting into permanent quarters. The roots when transplanted are set deep so that the upper portion is 6 to 8 inches below the surface of the soil, in order to permit surface cultivation without injury to the roots; they are set 18 to 24 inches apart in the row and the rows are 4 feet apart. The soil is regularly cultivated between rows at intervals during the first season. After the tops die in the fall and are removed, the entire surface is cultivated about 4 inches deep. Cultivation begins again the next spring and is continued as before.

(3) *Cutting shoots.*—A few shoots may be cut the second year, but regular cropping should not take place before the third year. Cutting should not usually continue longer than 4 to 6 weeks.

(4) *Fertilizers.*—In starting an asparagus planting, well-decomposed stable manure, when obtainable, should be applied to the plowed ground at the rate of 10 or 12 tons an acre and thoroughly worked into the soil before the roots

are planted; or the manure may be applied to clover sod and turned under the preceding fall; then one can apply 600 to 800 pounds of **Mixture No. 8** or **No. 9** (p. 603), according to soil conditions, in the spring before putting in roots. The purpose should be at the beginning to have an abundance of organic matter and available plant-food in a deep and mellow soil. In the absence of farm manure, use more of the fertilizer mixture. Then each spring apply 400 to 800 pounds of the same mixture. When well-decomposed farm manure is obtainable, it is a good plan to apply and harrow in early in spring and supplement with commercial fertilizer according to need. Just before the cutting season is over or soon after, it is important to make another application of fertilizer, the constituents of which should be largely in readily available form. For this purpose use 200 to 400 pounds of **Mixture No. 8** (p. 603). The significance of this later application should be understood. The constant removal of shoots during the cutting period is exhaustive to the plant and an abundance of plant-food is needed to give it chance to recover by making a vigorous growth during the rest of the season and storing nutritive material in the roots for the growth of shoots during the next cutting season. The application of plant-food is for two purposes: (1) To increase the yield by increasing the number and, particularly, the size of the shoots, and (2) to produce shoots of the highest possible quality in respect to flavor and tenderness. Small, insignificant-looking shoots generally indicate lack of nutrition or cultivation, or excessive cutting, etc.

Fertilizers do not control the color of the asparagus shoots. The matter of white or green shoots depends upon protection from, or exposure to, sunlight. The demand of the market determines which kind is most profitable to furnish.

Rhubarb, also commonly known as pie-plant, resembles asparagus as a garden crop, because it is early and because the tops are cut for use. It is the first fresh material of spring suited for making sauce and pie. It is now exten-

sively grown for canning and is used to some extent in making wine. The methods of setting roots, character of soil and methods of cultivation are essentially the same as for asparagus. When once established, the plants will survive much neglect, but they will respond profitably to good treatment. The methods used in supplying plant-food to asparagus apply equally well to rhubarb.

Garden-beans.—Edible garden-beans include (1) those

ABSENCE OF NODULES ON ROOTS OF PEAS NOT INOCULATED. MICHIGAN STATION

grown for use as string-beans, both fresh and canned, and (2) lima beans; the latter are grown in both poled and dwarf forms. Garden-beans respond to good soil conditions. The pole types especially make use of generous applications of plant-food. Although beans are able to utilize atmospheric nitrogen, it is nevertheless desirable, in growing garden varieties, to supply a liberal amount of nitrogen as well as phosphorus and potassium compounds and calcium carbonate. It is desirable to prolong the growing season

of the plant and keep it succulent as long as possible; this is accomplished by supplying the nitrogen quite largely in organic forms. **Mixtures No. 8** or **No. 9** (p. 603) can be used at the rate of 400 to 600 pounds an acre.

Field-beans are grown for the seeds and require treatment that differs considerably from the growing of garden beans.

(1) *Rotations for field-beans.*—The following serve as illustrations of rotations employed in bean-growing sections:

(a) Three years: Beans, 1 year; wheat, 1 year; clover, 1 year.

(b) Four years: Corn or potatoes, 1 year; beans, 1 year; wheat seeded with clover, 1 year; clover cut for hay and then plowed under, 1 year.

(2) *Soil and preparation.*—The soils best adapted to field-beans are well-drained clay loams; sandy or gravelly loams give good crops when kept well supplied with organic matter and plant-food. Soils that are extreme either in heaviness or lightness are undesirable, and also soils containing an excess of organic matter like muck or peat soils. Generally speaking, good corn or wheat land is good bean land. For best results, land should be plowed 4 to 6 weeks before planting, and should be put into good mechanical condition by harrowing to prevent growth of weeds and to hold moisture for the use of the crop.

(3) *Fertilizers.*—When beans are grown after clover or when farm manure is used, little nitrogen need be supplied in addition. On clayey soils, large amounts of potassium are not usually needed. As an application for field-beans, **Mixture No. 2** (p. 543) is suggested, at the rate of 200 to 400 pounds an acre, to be used at the time of planting or just before.

Garden-peas.—The statements made above in relation to garden-beans apply in most respects to the growing of garden-peas. Peas are grown as a field crop for canning purposes, the object being the same as with garden-peas,

that is, the production of a sweet, tender, well-flavored product.

Beets. (See page 606.)

Cabbage.—The growing of cabbage on a large scale has become a specialty in sections where soil and climatic conditions are favorable. Early cabbage is practically all used immediately, while the use of the late crop is distributed, some going to the table at once, some being made into sauer-

BACTERIAL NODULES ON ROOTS OF PEAS THAT HAVE BEEN INOCULATED. MICHIGAN STATION

kraut and some being put into storage for later distribution. Between the southern-grown and the early and late northern-grown crops, fresh cabbage is available to consumers at all times of year.

(1) *Crop-rotations for cabbage.*—Crop-rotation is desirable, not only for the sake of the physical and chemical factors in the soil, but as a means of protection against those insects and plant diseases that infest this crop. Probably

nothing is better to precede cabbage than clover sod, well-decomposed; and cabbage can therefore be made to fit into a great variety of rotations. Where long seasons prevail and cabbage is grown as an early crop, it can be followed in the same season by some other crop.

(2) *Soils and preparation.*—The qualities requisite in a soil adapted for growing cabbage as a farm crop are good drainage, abundance of available plant-food and structure suited to hold moisture. A considerable variety of soils meets these conditions. In the South, sandy soils are used in growing cabbage for the early northern market because they promote rapid growth at the right season and can be cultivated at a time when heavier soils cannot be. The soil, whatever its character, should be put into mellow, well-pulverized condition before setting out the young plants.

In A peas were grown without inoculation.
In B peas were grown after inoculation. MICHIGAN STATION.

(3) *Fertilizers.*—Large applications of farm manure (15 to 20 tons an acre) have been successfully used, and clover sod supplemented by 10 or 12 tons is desirable when practicable. Under such conditions, some commercial fertilizer can be used to advantage, especially one supplying phosphorus and potassium in larger proportions than nitrogen, say 400 to 600 pounds of Mixture No. 8 or No. 9 (p. 603) for farm-crop cabbages; for market-garden crops in the North raised for early market, larger amounts of fertilizer, the constituents of which are easily available, can be used, especially on light soils. Excessive supplies of nitrogen are to be avoided for the following reasons: (a) Rapid, early growth is promoted to such a degree that the cabbage does not form the close, solid kind of head that is desired.

(b) Even when head formation is not affected, the keeping-quality of the cabbage is lessened, owing to the extreme succulence and tenderness of the vegetable growth, an objectionable property in cabbages that are to be shipped long distances or kept some time before consumption. This quality of tenderness is, however, something desirable in the case of cabbages that are grown near market and for immediate consumption.

In the case of market-garden crops which have to depend largely upon applied fertilizers, 1,000 pounds or more of **Mixture No. 8** or **No. 9** can be used, being worked into the soil just before setting the plants. On light soils, further applications of top-dressings are sometimes recommended; for example, 75 to 100 pounds of sodium nitrate and 150 to 200 pounds of acid phosphate when the plants begin to show good growth after transplanting; and, after heads begin to form, 100 to 200 pounds more of sodium nitrate.

In the case of farm-crop cabbage, an application of 600 to 1,000 pounds of **Mixture No. 8** or **No. 9** (p. 603) can be used without further top-dressings, except under special conditions when the soil appears to be lacking in plant-food.

In case of cabbage grown in the South for early northern market, a fertilizer like **Mixture No. 9**, except that it contains only one-half the amount of nitrogen, is applied at the rate of 1,000 to 1,500 pounds an acre at the time of planting, followed by a top-dressing of 150 to 200 pounds of sodium nitrate, or equal parts of sodium nitrate and ammonium sulphate, when the growing season comes. The postponement of application of much nitrogen is to prevent so rapid growth of foliage as to make it too tender to resist the low temperatures of winter months.

(4) *Transplanting.*—When the young cabbage plants are being transplanted in the field, it has been found useful at the North in many cases to water the soil around each plant after setting with about one-quarter of a pint of solution made by dissolving one ounce of sodium nitrate in 3 or 4

gallons of water. This furnishes both moisture and plant-food, serving to make conditions favorable for a prompt start.

(5) *Cultivation.*—Cabbage needs frequent and thorough but not deep cultivation. To destroy weeds and maintain a loose, two-inch earth-mulch which will prevent evaporation of water is the object of cultivation. As grown in the South, however, cultivation is postponed until spring, when active growth begins.

Cauliflower is very closely related to cabbage in respect to soil, fertilizer requirements, cultivation, etc. Special skill, as the result of experience, is often required to grow cauliflower successfully. For best results, a cool, moist season is needed.

Brussels sprouts are treated in much the same manner as cabbage in respect to fertilization, cultivation, etc. The plants are set out somewhat later than cabbage.

Celery is a plant in which certain qualities are peculiarly essential as an article of diet. As it is eaten raw, imperfections in quality are more prominent than in the case of those vegetables the poor qualities of which can be modified by cooking. Good celery must be tender, crisp, sweet and mild in the characteristic celery flavor. Celery is of poor quality when the stalks consist largely of bundles of tough fibers, without sweetness and of so strong a celery flavor as to be bitter, pungent and generally disagreeable. The good quality of celery depends largely upon an abundant supply of moisture and readily available plant-food adapted to promote rapid growth.

(1) *Soil.*—Land which is ordinarily called "celery land" consists of reclaimed swamp-land; it is heavily loaded with decomposed organic matter and usually contains considerable nitrogen, largely in forms not quickly available. Such lands are generally deficient in potassium and phosphorus. Celery grows well on uplands, the soil of which is deep, well supplied with plant-food, mellow, loose and well-drained.

(2) *Fertilizers.*—Extremely large amounts of plant-food

materials are often supplied celery crops, 2,000 pounds an acre not being uncommon of such a fertilizer as **Mixture No. 8** or **No. 9** (p. 603) applied at the time of setting the plants. A few top-dressings of sodium nitrate, 100 pounds an acre each time, well worked into the soil on both sides of the rows, promote the rapid growth requisite for fine quality. It must be kept in mind that abundance of water is just as essential as plant-food. Some growers apply the whole amount of fertilizer about a week before putting in the crop, while others apply one-half before putting in the crop, and the remaining half later in two equal parts.

Cucumbers are used for pickling, in making salads, and as a relish. In some localities large quantities are grown solely for pickling. The vines are very sensitive to frost. For best results, the soil should be a warm, sandy loam, though the crop does well on clay soils. Generally speaking, land suited to corn is adapted to cucumbers. The crop is planted early in spring when danger from frost is past. The soil is thoroughly prepared as in case of corn (p. 576). When practicable, as in gardens, it is common to make a hole in the soil where the seed is to be planted and to place a shovelful or so of well-decomposed farm manure or compost in the hole and cover with about 2 inches of earth before planting the seed; this is especially useful in poor soils. The same result can usually be accomplished by simply working the manure into the soil.

Fertilizers.—Farm manure and leguminous green-crop manure are necessary on poor soils, since there should be an abundance of organic matter. When cucumbers are grown for table use, the fertilizers should be such as to promote steady rather than rapid growth of vines; the nitrogen is preferably in organic form for the most part and also a portion of the phosphorus. From 400 to 800 pounds of **Mixture No. 9** (p. 603) can be applied to the soil and worked in previous to planting. In case the crop is grown for pickles, the chief purpose is a large setting and quick growth of small, green cucumbers, and this is promoted by applications

of nitrate. For this purpose, one can use 400 to 800 pounds or more of **Mixture No. 8** (p. 603).

Pumpkins and squashes are grown under conditions of soil, plant-food supply, etc., essentially the same as in the case of cucumbers. They are now extensively grown for canning as material for pie-making. Pumpkins are also used to a considerable extent as cattle-food. The custom of growing pumpkins in corn-fields is a poor one for several reasons; much better and larger crops can be obtained when

EXPERIMENTS IN VARIETIES OF WATERMELONS. GEORGIA STATION.

grown alone. Summer squashes are rapid growers, for which **Mixture No. 8** is adapted, while the winter varieties have a much longer growing period; the latter can, therefore, be supplied more largely with organic nitrogen and some phosphorus in form of tankage as in **Mixture No. 9** (p. 603).

Muskmelons.—The growing of muskmelons or cantaloupes has become a market-garden or truck-growing specialty in some localities where soil and climate make it possi-

ble to put them into northern markets in summer. The soils best adapted to muskmelons are warm, sandy loams. It is one of the crops requiring a long season for maturity, and plant-food nitrogen can therefore be supplied in organic forms in large part. As in case of cucumbers, pumpkins, etc., muskmelons require a large amount of organic matter in the soil. Manure can be placed in a hole and covered with soil to a depth of 3 or 4 inches and the seeds planted on this and covered with 2 or 3 inches of additional soil. A more convenient method is to apply the manure in liberal amounts to the portions of plowed ground where the rows are to be planted and work it into the soil very thoroughly. In addition, 600 to 1,000 pounds of **Mixture No. 9** (p. 603) can be used. In the absence of manure, some leguminous green-crop manure should be used to furnish organic matter and well-decomposed before planting. In this case, an application of 600 to 800 pounds of **Mixture No. 9** can be broadcasted and harrowed in before seeding and an additional handful worked into the soil where the seed is to be planted. This can be followed by a top-dressing of the same mixture worked into the soil around each hill about 4 weeks after planting.

Watermelons.—The statements under muskmelons apply to the growing of watermelons.

Sweet corn, primarily grown for table use when fresh, is now more extensively grown for canning. Most of the sweet corn thus used is grown as a regular farm crop. Sweet corn is sometimes grown for fresh green forage and for silage, but, on account of its smaller yield, it is not so well adapted for green forage as are the varieties regularly used for forage purposes. When sweet corn is raised for canning, the stalks and leaves can be fed after the ears have been removed. Sweet corn of fine flavor and satisfactory sweetness can be raised only in a northern climate.

In respect to crop-rotation, soil preparation and cultivation, the same conditions apply as in the case of field corn (p. 575). A succession of plantings, especially of different

varieties, will secure a continuous supply whether for market or for home use. When grown as a market-garden crop, it is important to push it to as early maturity as possible in order to obtain the best prices.

Fertilizers.—There is a marked difference in the objects in view as between field corn and sweet corn. In one case, a ripened crop is the object; a large part of the growth is made during the months of July and August, and the growing season is relatively long. Field corn can, therefore, utilize forms of plant-food that become available gradually during the growing season. Sweet corn, on the other hand, is harvested before it reaches maturity and after a period of growth in which field corn makes only a comparatively small part of its development. Sweet corn, like most other garden crops, should make an early and rapid growth. Part of its nitrogen should, therefore, be nitrate, in order to supply needed nitrogen before nitrification becomes active. Phosphorus in soluble compounds must be supplied in considerable amounts to promote early and continuous growth. Potassium is essential for the production of starch and sugar. An application of **Mixture No. 8** (p. 603) is recommended at the rate of 500 to 800 pounds an acre, harrowed into the soil just before planting.

Lettuce of good quality is tender and crisp. These qualities can be secured only by an abundant supply of plant-foods which promote rapid and continuous growth. Interruption of steady growth results in fibrous, tough character of leaf and bitterness of taste. Clay loams with abundance of organic matter are adapted to lettuce growing. Some growers use as much as 1,500 to 2,000 pounds or even more per acre. Ordinarily, on good soils, an application of 800 to 1,200 pounds per acre of **Mixture No. 8** (p. 603) will be found sufficient, especially if supplemented by two or three applications of sodium nitrate (p. 532) at the rate of 100 pounds an acre, after the crop is well started, at intervals of 10 days or 2 weeks; it can be distributed broadcast along the

rows and well worked in. Some growers in using large amounts of a complete fertilizer put it all on the soil in one application about one week before putting in crop. Others use the same amount in three applications, putting on one-half a week before putting in the crop and the remaining half in two subsequent equal applications.

Spinach is used for cooking in the form of greens. The conditions of soil, growth, cultivation and treatment with fertilizers are essentially the same as for lettuce.

GROWING ONIONS FOR SEED. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

Onions are now grown as one of the specialties by market-gardeners and to some extent by farmers engaged in raising general crops, where soil and climatic conditions are especially favorable.

(1) *Crop-rotation for onions.*—Generally speaking, the rotation for onion crops should be such that the soil will be as free as possible from weeds and well provided with organic matter. A second crop of clover, well covered with

farm manure in the fall and plowed, followed by potatoes the next season, makes a good preparation for onions the year following.

(2) *Soil and preparation.*—Rich, well-drained loams, with abundance of organic matter, are best adapted to onions. Some soils suited to celery are used also for onions, especially deep, rich muck soils that have been under crops for a few years, and in which the water-level is about 2½ feet below the surface of the soil. The soil should be made mellow and well pulverized as for most garden crops.

(3) *Fertilizers.*—Farm manure, when used, is best applied to a preceding crop. With a soil containing an abundance of organic matter, 800 to 1,200 pounds per acre of **Mixture No. 8** (p. 603) can be used, being applied broadcast and well worked in before planting. In the case of very early onions, where rapid, early growth is important, **Mixture No. 8** can be used, supplemented with 50 to 100 pounds of sodium nitrate per acre after the crop is well started, and another similar top-dressing 2 or 3 weeks later (p. 532).

(4) *Seeding.*—The seed should be put in the ground as early as the land can be properly prepared. When done in the ordinary way, the rows are 12 to 14 inches apart for hand cultivation or 30 inches for horse cultivation. About 18 to 30 seeds are sown per foot and covered 1 inch. From 3 to 6 pounds an acre are used.

Another method is to start the onions with seed sown in a greenhouse or in hotbeds about 6 weeks ahead of usual time for seeding and then transplanting in the field as soon as soil conditions are suitable.

The early small table onions that are served raw are generally grown from sets, or little bulbs, which are produced by drilling in 30 to 40 pounds of seed per acre; the very thick seeding results in the production of very small bulbs, which are harvested in August or September. The thick seeding is for the purpose of preventing the sets becoming too large under generous application of plant-foods. Another method

of seeding for sets is to sow the seed thickly in rows about 3 inches wide with a distance of about 8 inches between rows. When these little onions, called sets, are put in the field 2 or 3 inches apart and about 3 inches deep, a new bulb is formed which is ready for the table early in summer. In the South, sets may be planted in the fall. As stated above, rapid, early growth is desirable and should be promoted by

EXPERIMENTS WITH TOMATOES

Each pile of tomatoes was raised on the same area of land and a complete fertilizer was used in each case. The small pile was grown by pruning to single stem and staking, without mulching or irrigation. The large pile was grown on untrained vines which were mulched with straw and surface irrigated. GEORGIA STATION.

liberal applications of readily available plant-food **Mixture No. 8** (p. 603), followed by a top-dressing of 100 pounds of sodium nitrate per acre, when growth is well started.

Tomatoes are grown very widely in the United States both in home gardens and as a field crop. More tomatoes are canned than of any other vegetable.

(1) *Crop-rotations for tomatoes.*—Generally speaking,

tomatoes can replace potatoes in rotation with other crops (p. 498).

(2) *Soil and preparation.*—Tomatoes grow on a great variety of soils from heavy clays to light, sandy soils. For field crops to be used in canning, good clay loams furnish large yields. For early tomatoes, warm, light, well-drained, rich sandy loams are requisite. Ordinarily, any soil that raises good crops of potatoes is adapted to growing tomatoes. The methods of preparing soil for tomatoes are essentially the same as in the case of potatoes (p. 600).

(3) *Fertilizers.*—The amounts and kinds of plant-food materials depend, of course, upon the character and condition of the soil and also upon the length of the growing period.

For early tomatoes, on soils which from previous treatment are known to be well supplied with phosphorus and potassium, an application of 400 to 600 pounds of **Mixture No. 4** (p. 562) may be used at the time of transplanting; or one-half of this amount may be used at that time and the other half 3 or 4 weeks later. In the case of soils in good mechanical condition but deficient in available plant-food supply, apply 500 pounds of **Mixture No. 8** (p. 603) per acre just previous to setting the plants and work it well into the soil; then, after the plants are set, apply around them 50 to 75 pounds of sodium nitrate per acre (p. 532). In 3 or 4 weeks, apply 75 to 150 pounds more of nitrate an acre around the plants, taking the usual precautions. This method insures quick growth from the start without risk of the excessive growth of vine that comes from exclusive or excessive use of sodium nitrate.

When farm manure is used, it should be distributed uniformly over the entire surface of the soil and thoroughly worked in before plants are set, using not more than 10 or 12 tons per acre. The nitrate is then applied as directed above. Excessive use of fresh manure must be avoided for early tomatoes, since the urinary nitrogen tends to promote

excessive growth of leaves and stems at the expense of fruit and also delays the formation and ripening of fruit. Therefore, whenever fresh manure is used at all extensively, generous applications of phosphorus and potassium compounds should be made in order to prevent the effects that come from the presence of a proportion of nitrogen too large in relation to phosphorus and potassium (p. 517).

For late tomatoes, on good soils, 500 pounds of **Mixture No. 8** (p. 603) can be used; on poorer soils, 1,000 pounds of **Mixture No. 9** (p. 603).

Eggplant.—In general treatment and culture, eggplant resembles the tomato, with the exception that its growing season is longer and on this account **Mixture No. 9** is used.

TABLE 61—APPROXIMATE AMOUNTS OF PLANT-FOOD CONSTITUENTS IN ONE CROP

Crop	Portion	Yield per acre	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
			Lbs.	Lbs.	Lbs.
Asparagus	Tops	2000 lbs.	7.0	2.0 (0.9P)	5.0 (4. K)
Beans, string..	Green pods	4000 "	10.0	3.2 (1.4P)	12.0 (10. K)
Beans, field ...	Seeds	25 bu.	60.0	18.0 (8. P)	19.5 (16.2K)
" "	Straw	2000 lbs.	28.0	6.0 (2.6P)	38.0 (31.5K)
Total			88.0	24.0 (10.6P)	57.5 (47.7K)
Beets, garden .	Tops & young beets	5000 lbs.	17.5	5.0 (2.2P)	32.5 (27. K)
Cabbage	Heads	20000 "	60.0	20.0 (8.8P)	80.0 (66. K)
Cauliflower ...	"	15000 "	42.0	15.0 (6.6P)	50.0 (42. K)
Celery	Tops	10000 "	25.0	20.0 (8.8P)	75.0 (62. K)
Corn, sweet...	Ears	4000 "	18.0	8.0 (3.5P)	12.0 (10. K)
Cucumbers ...	Edible part	100 bu.	5.5	3.3 (1.4P)	11.0 (9.1K)
Eggplant	" "	4000 lbs.	8.0	2.0 (0.9P)	12.0 (10. K)
Lettuce	Leaves	8000 "	20.0	6.4 (2.8P)	36.0 (30. K)
Onions	Bulbs	300 bu	39.3	15.4 (6.8P)	37.6 (31.2K)
Muskmelons ..	Fruit	10000 "	22.0	8.0 (3.5P)	40.0 (33. K)
Peas, garden ..	Green seeds	1000 "	11.5	3.0 (1.3P)	4.5 (3.7K)
" "	" pods	4000 "	10.0	2.0 (0.9P)	8.0 (6.6K)
Total		5000 "	21.0	5.0 (2.2P)	12.5 (10.3K)
Pumpkins	Fruit	20000 "	32.0	14.0 (6.2P)	52.0 (43. K)
Rhubarb	Stems	20000 "	20.0	8.0 (3.5P)	70.0 (58. K)
Spinach	Stems & leaves	10000 "	50.0	15.0 (6.6P)	25.0 (21. K)
Tomatoes	Fruit	250 bu.	30.0	10.5 (6. P)	52.5 (43.5K)
Watermelons..	Fruit	20000 lbs.	34.0	12.0 (5.3P)	60.0 (50. K)

CHAPTER XXXIII

GREENHOUSE CROPS, NURSERY CROPS AND ORNAMENTAL PLANTS

The plant-food needs of the plants embraced under the heading of this chapter have received much less systematic, experimental study from trained investigators than any other class of agricultural crops. The practices commonly followed are based largely on tradition and, while representing the results of extended observation and experience, they are undoubtedly susceptible of much improvement, if we may judge from the eagerness with which every reasonable suggestion is accepted and tested by those most interested in these crops. Outside of the natural soil supply, farm manure has been depended on as the chief source of plant-food.

It is our purpose to bring together such information as is available in relation to the feeding of these crops and especially in respect to the manner in which commercial fertilizing materials can be utilized.

GREENHOUSE CROPS

Crops grown under glass for commercial purposes include vegetables, flowers and, to some extent, non-flowering ornamental plants. The vegetables most commonly raised as forcing-house crops are lettuce, tomatoes, cucumbers and radishes. With the recent, rapid development of truck-gardening in the South, the number of greenhouse vegetables that can be grown to commercial advantage in the North has been necessarily limited. The flowers that are most extensively grown are roses, carnations, violets and chrysanthemums. All sorts of potted

plants, flowering and non-flowering, are grown, most of which find their way as house plants into the homes of purchasers, most of whom have little or no knowledge in regard to the methods of feeding plants of any kind.

Economy of time is an important factor in relation to forcing-house management, the main object being to push a crop to its marketable condition as rapidly as consistent with quality of product. The general purpose is

GRAPERY. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

somewhat the same as in case of early market-garden crops, but in the greenhouse every effort is made to have all conditions, as far as possible, under strict control so as to promote rapid growth. The amount of soil used is comparatively insignificant, especially when we consider the vegetable growth often taken from it in comparison with the same area of field soil. Such rapid, large growth of plant material in the quickest time possible means generous amounts of quickly available plant-

food supplies. While nitrogen, phosphorus and potassium form only a small fraction of the actual substance of the plant itself, we must remember that the processes of assimilation, upon which plant growth depends, are largely controlled by the amounts of these plant-food constituents that are ready at just the time needed and in sufficient amounts. Greenhouse crops, in order to grow quickly and satisfactorily, must be well and properly fed.

Before taking up special crops for detailed study, we will discuss in a somewhat general way the relations of soils and fertilizers to forcing-house plants.

Soils.—For growing plants under glass, soils should be rich in well-decomposed organic matter, which is often mentioned in greenhouse literature as "fibrous material." The origin and the properties of organic matter in soils have been fully discussed elsewhere (p. 117). This is essential to a mellow and porous soil, properties which forcing-house soils must possess. Organic matter may be supplied by means of grass sod, horse or cow manure, leaf-mold, finely divided peat or muck, etc. Whatever its source, it is essential that the organic matter be so completely decomposed that all coarse material shall have largely lost its original structure, and become soft and of fine texture. Too much clay is undesirable, since it produces too great compactness in the soil, interfering with the extension of growing rootlets, lacking in sufficient circulation of air, holding water too tenaciously, hardening on the surface, etc. On the other hand, too much organic matter in the form of coarse, undecomposed farm manure is undesirable, since it causes too much looseness, which results in excessive ventilation and too rapid drying. Greenhouse soil is, however, essentially artificial and is, therefore, under much better control than the soil of fields. Good soil is ordinarily made by combining rich garden loam or

decomposed sod, sharp sand, and well-decomposed organic matter containing considerable nitrogen, as in case of farm manure, which is the material commonly used. There may be added also some fine bone-meal or bone-flour for the special purpose of furnishing phosphorus, with some additional nitrogen. Finely-ground charcoal is used in some cases to increase porosity as well as water-holding power. Other materials are used for special purposes in case of individual crops. The proportions of different materials are made to vary to suit the special requirements of each crop, being made heavier or lighter or richer in organic matter, etc.

As a type of preparation commonly used for general greenhouse purposes, the following mixture will serve: One third, each, of (1) mellow garden soil, or well-decomposed grass sod, (2) sharp sand, and (3) well-decomposed cow, horse, or mixed farm manure. In preparing the decomposed sod and manure, the sod may be cut and made into a pile to decompose by itself, and the manure into a separate pile under proper precautions (pp. 316-327). These are forked over occasionally and finally mixed when ready for use. Another, and usually preferable, method is to compost the sod and manure together, forking over a few times to promote decomposition (p. 325), and mixing with garden soil and sand in desired proportions when ready for use. The constituents should be thoroughly mixed. When completed, the soil is put into beds or benches to the depth of 6 to 8 inches; the same kind of soil is used for potted plants.

It is common to clean out the benches and change such soils every year, because, as a result of cropping, the soil is apt to be impaired in its physical properties and chemical composition and, in part, because it is usually infested with germs of plant diseases and insects or their eggs. Remaking is usually easier and safer than trying to restore used soil. There is more or less prevalent a

practice of restoring used greenhouse soils by sterilization with steam, both before its first use and also in the way of renewal. This has the advantage of killing insect pests, undesirable micro-organisms and weed seeds; but desirable forms of life are also destroyed, such as decomposing, ammonifying and nitrifying organisms (pp. 198-210). These can, however, be easily introduced again by treatment with a small amount of good stable manure.

It is interesting to call attention, in this connection, to the fact that excellent results have been obtained by departing wholly from the traditional method of preparing greenhouse soils, making up a purely artificial soil from such materials as sifted coal-ashes, sand, peat-moss, etc., which contain little plant-food, and treating with commercial fertilizing materials.

In the absence of farm manure or other desirable form of organic matter, any rich garden loam can be successfully used for ordinary greenhouse work by mixing it thoroughly with plant-food materials at the time of filling the benches or pots and then keeping it well supplied with additional plant-food materials after the plants are well started. However, in growing some special crops, like certain cut flowers and vegetables, much care must be taken to have the soil possess certain, definite characteristics in respect to texture and structure (p. 101). In using such soil one can at the time of filling the beds use for each 100 square feet 1 or 2 pounds of **Mixture No. 10 A** (p. 609), applying this or some other mixture once in 10 to 15 days in the amounts and manner indicated (p. 649). It is essential to keep plenty of organic matter in the soil; and, when the soil is made up, the use of a pound or so of fine-ground limestone or marl may be found advantageous.

Fertilizers.—Before discussing the use of specific plant-food mixtures for individual greenhouse crops, we will

call attention to some general features, which will be taken up in the following order: (1) Farm manure, (2) wood-ashes and bone-meal, (3) commercial plant-food materials, (4) when to begin feeding, (5) overfeeding, (6) relations to light, temperature and moisture, (7) liming.

(1) *Farm manure* is used in three ways: (a) As a part of the greenhouse soil introduced when the soil is made; (b) as a mulch after plants are well rooted; (c) as water-extract. The first method of use has been dwelt upon already. When used as a mulch, well-decomposed horse, cow, sheep, or mixed manure is applied to the soil surface in a layer not over half an inch deep; it is generally best to sterilize manure by steam before using it as a mulch. When the manure mulch has largely disappeared, a second application may be made, and with some crops, further additions.. When used as a mulch, manure rich in urinary nitrogen may give off ammonium carbonate to such an extent as to injure the mulched plants, especially when used in considerable amounts and in a very warm place.

Water-extract of animal manures, commonly known as *liquid manure,* has been the chief source of plant-food in traditional forcing-house methods. Several ways of preparing liquid manure are used, but the product is, of necessity, very variable in composition, owing to variation in the composition of the material extracted. The following method is probably as good as any: For 50 gallons of water use 20 pounds of comparatively dry, well-decomposed horse, or cow, or mixed manure, or 10 to 12 pounds of pulverized sheep manure, or 5 to 8 pounds of air-dried hen manure. For convenience, the manure, placed in a coarse gunny sack, is soaked in the 50 gallons of water for two or three days; the sack is occasionally moved up and down vigorously in the water and the contents are stirred and mashed with a blunt stick. Larger

amounts of manure may be used for the same amount of water and then diluted before application, enough to make it the proper strength. This water extract is used on soils once in a week or ten days, the treatment depending upon the crop. Fresh manure is not used for making the water extract, because its urinary nitrogen, changing into ammonium carbonate, makes a solution

FEEDING AND VARIETY EXPERIMENTS WITH CAULIFLOWER AT ARLINGTON FARM. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

which has to be employed with extreme care for fear of overfeeding with nitrogen or of burning the plants.

(2) *Wood-ashes and bone-meal.*—In addition to farm manure, there have been used more or less extensively for greenhouse crops wood-ashes and bone-meal. These are applied to the surface of the soil and worked in lightly. Wood-ashes furnish potassium, a very small

amount of phosphorus and considerable amounts of calcium carbonate. The good effect of wood-ashes, usually ascribed to potassium, is probably more often due to the results of neutralizing soil acidity by both the potassium and calcium carbonate and making conditions more favorable for the process of nitrification (p. 204). The uncertain composition of wood-ashes, together with their high price in relation to their plant-food value, often makes their use unsatisfactory.

Bone-meal has been used in large amounts in greenhouse soils. Raw bone-meal is less quickly available than the steamed (p. 435), though it contains more nitrogen. Probably, bone-flour gives the best results, when all things are considered. Bone products should be free from salt for greenhouse use. They have the following advantages: (1) They are lasting on account of their moderate availability; (2) they furnish phosphorus, and some nitrogen; (3) they can be used in fairly large amounts without burning or otherwise injuring crops; (4) they are in a convenient form to apply. It appears to be the custom among many to regard bone-meal as a general cure-all and to resort to its use for all possible purposes.

(3) *Commercial plant-food materials.*—Under this division, we will discuss the following topics: (a) Different materials, (b) plant-food mixtures, (c) application.

(a) Different materials.—There can be used the various materials already mentioned (pp. 244-287) and there are additional ones which, while too expensive for field purposes, may not be found too extravagant for some forms of greenhouse crops. In order that a reasonably complete list may be at hand for easy reference, we include those already given, as well as several not previously mentioned which may be used for experiment.

TABLE 62—LIST OF PLANT-FOOD MATERIALS FOR SPECIAL GREENHOUSE WORK.

Materials	Nitrogen	Phosphoric acid	Potash
	Per cent.	Per cent.	Per cent.
CONTAINING NITROGEN			
Ammonium sulphate (p. 246).........	20 to 25		
Ammonium nitrate (p. 251)...........	32 to 35		
Sodium nitrate (p. 244)..............	15 to 16		
CONTAINING PHOSPHORUS			
Acid phosphate (p. 271)..............		14 to 16 (6.5P)	
Double superphosphate (p. 275).......		40.0 (17.5P)	
Di-sodium phosphate (Na_2HPO_4) dry..		50.0 (22. P)	
Tri-sodium phosphate (Na_3PO_4) dry..		43.0 (19. P)	
CONTAINING POTASSIUM			
Potassium chloride (p. 279)...........			50.0 (41.5K)
Potassium sulphate (p. 280)...........			48.0 (40. K)
CONTAINING NITROGEN AND PHOSPHORUS			
Ammonium phosphate ($(NH_4)_3PO_4$)....	35.0	47.5 (21. P)	
CONTAINING NITROGEN AND POTASSIUM			
Potassium nitrate (p. 252)...........	13.0		44.0 (36.5K)
CONTAINING POTASSIUM AND PHOSPHORUS			
Di-potassium phosphate (K_2HPO_4) dry		40.7 (18. P)	22.5 (18.7K)
Tri-potassium phosphate (K_3PO_4) dry		33.4 (14.7P)	39.0 (32.4K)

P, phosphorus. K, potassium.

While some of these materials, such as ammonium phosphate and the potassium phosphates, are at present found only in pure, high-priced forms, a cheaper commercial product could be prepared at reasonable cost, if there were sufficient demand. The ordinary dry sodium phosphate of the drug-stores is the di-sodium phosphate and contains about 40 per cent. of phosphoric acid (18P); this can be purchased in large amounts from manufacturing drug and chemical houses at prices that make the material available for some purposes. This compound has the advantage of dissolving easily in water.

From the above list, four compounds can be selected possessing ideal qualifications, from a chemical point of view, for use in feeding plants: Ammonium nitrate, ammonium phosphate, potassium nitrate and potassium phosphate. They possess two marked advantages: (1) Easy solubility, and (2) freedom from constituents not used by plants. In most of the plant-food materials we

use, we are compelled for the sake of economy to use compounds containing constituents we do not need to use, such as chlorine in potassium chloride, sulphuric acid in potassium sulphate, sodium in sodium nitrate, gypsum in superphosphates, etc. These constituents are largely left in the soil and may or may not be desirable, according to special conditions. In using compounds like the four mentioned above, the constituents are all plant-food and no residues of useless or objectionable materials are left in the soil. They can all be applied in solution and their amounts closely regulated.

Prejudice against the use of so-called chemicals has been very general and probably is still. This is due to lack of familiarity with their use and the tendency to use too strong applications. Few appreciate that these materials are extremely concentrated and are most useful only when very dilute; when used otherwise, they are poisons.

(b) Plant-food mixtures for greenhouse crops.—Several fertilizer formulas have been published for use, especially in growing flowers under glass. These vary greatly. Some are apparently based on formulas for field crops containing about 1 part of nitrogen, 2 of potash and 3 of phosphoric acid. One formula which has found extensive use contains 1 part of phosphoric acid, 2 of potash and 3 of nitrogen, having the relative amounts of phosphorus reversed in comparison with the preceding, a proportion based apparently on the composition of some plant. Another writer has published four mixtures for one special plant, representing plant-food constituents in three different sets of proportions.

Recognizing the fact that forcing-house soils are made rich in nitrogen, it is a safe basis to assume that one needs to apply only about one-half the amount of nitrogen which one would use on an ordinary soil. On this assumption, a plant-food mixture adapted for general

forcing-house use would contain 1 part of nitrogen to 2 parts each of phosphoric acid and potash or, if represented by a formula, 4 per cent. of nitrogen, 8 of phosphoric acid (3.5P) and 8 of potash (6.5K), which is so nearly like the plant-food proportions in our **Mixture No. 8** (4—8—10, p. 603), that we can safely adopt it with some modifications as to materials, when desired for special conditions. With materials better adapted to greenhouse uses, we suggest the mixtures given below. It should be stated that when using bone-meal we apply larger amounts than called for, on the ground that only a little more than one-half of the phosphorus becomes available to the growing crop. The bone is assumed to be steamed bone-meal or flour, containing about 2 per cent. of nitrogen and 20 of phosphoric acid. The amounts of materials are given on the basis of one ton, but can easily be reduced to a basis of 100 pounds, or such other amount as one may desire to make.

Plant-food mixture No. 11 A.—*For general use with forcing-house crops.*

Sodium nitrate......	300 lbs.	(45 lbs. nitrogen)
Ammonium sulphate.	100 "	(20 " "
Acid phosphate	500 "	(70 " available phosphoric acid, or 31 lbs. P)
Bone flour (2N–20P$_2$O$_5$)	700 "	(140 " phosphoric acid (62P) and 14 lbs. nitrogen)
Potassium sulphate..	400 "	(200 " potash, or 165 lbs. K)

This mixture is to be applied dry on the surface and worked lightly into the soil, using at the rate of 16 to 24 ounces for 100 square feet of soil. It can be used when only moderate rapidity of action is desired.

Plant-food Mixture No. 11 B.—*Applied in solution for use when quick action is desired.*

Sodium nitrate	250 lbs.	(40 lbs. nitrogen)
Potassium nitrate	950 "	(120 " " and 400 lbs. potash, or 332 lbs. K)
Di-sodium phosphate (dry)..	800 "	(360 " phosphoric acid, or 160 lbs. P)

Owing to the concentrated form of the materials used, one ton contains twice as much nitrogen, phosphorus and potassium as the preceding mixture and, moreover, all

of it goes into solution, while in A only a little over one-half is water-soluble. This is therefore applied in smaller amounts; 6 to 8 ounces are dissolved in 50 gallons of water and applied to 100 square feet of soil surface.

Plant-food Mixture No. 11 C.—*Applied in solution for use when less rapid action of nitrogen is desired.*

Sodium nitrate........	150 lbs.	(22 lbs. nitrogen)
Ammonium sulphate ..	300 "	(60 " ")
Acid phosphate	1150 "	(160 " available phosphoric acid, or 70 lbs. P)
Potassium sulphate ...	400 "	(200 " potash, or 165 lbs. K)

The rate of application is 12 to 16 ounces in 50 gallons of water for 100 square feet of soil surface.

For greenhouse soils consisting of good garden loam without admixture of manure, **Mixture No. 4** (p. 562) can be used at the rate of 16 to 24 ounces for 100 square feet of soil, sprinkling on the surface and lightly working in, or dissolving in 50 gallons of water before applying.

When one is using a solution regularly, it will be convenient to dissolve it in larger amounts and store the solution in a tank. The solution should be well stirred from the bottom of the tank before using, if it has been undisturbed for two or three days. The solution may thus be stored in more concentrated form and diluted properly before applying.

(c) Application of plant-food mixtures.—In making applications of soluble compounds to greenhouse soils, one is partly guided in respect to the amount of application by the fact that the feeding roots of plants are liable to injury when the soil solution is more concentrated than 1 pound of soluble matter in 500 pounds of water. There is a greater liability to harm in case of soils deficient in organic matter or humus, especially light soils. This relation has been taken into consideration in giving the amounts stated above. In the use of any kind of plant-food in solution, care must be taken not to begin with too strong a solution. In forcing-house work, it is easy to make application of plant-food, especially in solu-

tion, and the principle is carried out of making several applications of a more dilute solution instead of more concentrated solutions at longer intervals. A rule used by some is to dissolve the plant-food material at the rate of 1 ounce in 1 gallon of water and apply 2 quarts per yard of soil surface, which is at about the rate of 5½ ounces for 100 square feet.

It is best not to make applications of plant-foods on very hot or on very cloudy days; in one case, the plant-food constituents are absorbed too rapidly, while in the other there is danger of suffocation of roots.

Frequency of application is governed largely by the kind of crop one is growing. Ordinarily, when vigorous feeding is desired, applications are made at intervals of 7, 10 and 14 days, as long as necessary to secure the desired results.

Feeding of forcing-house crops is usually begun only after growth is well started, and the soil well filled with roots. If, at any time, plants show signs of overfeeding with nitrogen (p. 412), the quickest way is to apply a solution of 8 ounces of acid phosphate and 2 ounces of potassium sulphate dissolved in 50 gallons of water for 100 square feet of soil surface.

Roses.—(1) *Soil.*—For forcing-house purposes, roses may be grown on a great variety of soils. Some varieties (Perle des Jardins, La France, Duchess of Albany) are said to do better on lighter loams, while a rather stiff loam is better suited to others (Brides, Mermets, Madam Hoste, Gontier, Souvenir de Wootton, and American Beauty). The soil is best prepared by taking a moderately heavy loam sod, cutting in the fall and composting with cow or horse or mixed manure, 3 parts of sod soil to 1 part of manure. This is turned and mixed two or three times during the winter, care being taken to make the condition as fine and uniform as possible. To each cubic yard of compost, one adds one pound of finely pow-

dered potassium sulphate, and 10 to 15 pounds of fine steamed bone, free from common salt, at the time of the last forking over, which should be some weeks before the compost is to be used. The bone is thoroughly mixed into the compost. Such a mixture is suited to plants that have been grown in 3 to 4-inch pots. The soil used for potting should be completely rotted sod mixed with one-sixth to one-eighth thoroughly rotted cow, horse, or mixed manure, without other addition. Soil sterilization is common.

(2) *Fertilizers.*—When plants are well started, filling the soil with roots, then one may begin to feed, using a manure mulch a couple of times, like that already described (p. 643). Later, usually in December or January, mulching is discontinued and feeding begun either with water-extract of manure (p. 643) or with one of **Mixtures No. 11 A, B, C,** or with combinations or alternations of the liquid manure and plant-food mixtures. Applications are made at intervals of 10 days or 2 weeks according to the behavior of the crop. When the plants have taken on a heavy growth, the frequency of application may be lessened. When at any time growth is slow, due to cold or cloudy weather, the applications should be withheld until active growth calls for more food. If at any time, too much of a concentrated fertilizer has been used, the effects can be counteracted by sowing some quick-growing grass or other plant; or, when conditions allow, the soil can be thoroughly soaked with water, thus reducing the concentration of the soil solution. The use of a complete plant-food mixture should enable one better to control plant growth than when one depends on the exclusive use of liquid manure.

Violets.—(1) *Soil.*—These grow well either in a sandy or gravelly or in a good clay loam like that preferred by most roses. Pains must be taken in the case of sandy soils to have plenty of partly decomposed organic matter,

which may be furnished by 1 part of manure to 3 parts of soil. In general, a compost may be made just as in the case of soil for roses, except that other fertilizing materials are omitted. Violets must not have soil too rich in nitrogen. It is important that the compost be well treated with slaked lime as it is made up. Sterilization of soil is useful in killing insects and disease germs.

YOUNG CARNATION PLANTS. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

When the soil is properly made, violets are not given additional feeding; but, when necessary, liquid manure prepared as described is applied not more frequently than once in three weeks, and then only during active growth or when vigorous development of leaf is desired. Lack of phosphorus is indicated by reddening of leaves along the veins and a delayed development of flowers; when this occurs, phosphorus is supplied by use of fine bone-flour or of basic-slag phosphate at the rate of 1 pound

to 30 square feet; or acid phosphate can be applied at the rate of 10 ounces for 100 square feet, either sprinkled on the soil between the rows or dissolved in 50 gallons of water; but if the soil does not contain enough calcium carbonate, an application should be made by putting 1 peck of freshly slaked lime in 50 gallons of water and applying this to 200 feet of soil several days before the application

CARNATIONS UNDER HIGH CULTURE. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

of superphosphate in order to decrease the availability of the phosphorus. Generally, it is found that two or three applications of superphosphate at intervals of two or three weeks are enough. If the soil is found too rich in nitrogen, treat it as previously directed. It is suggested that experiments be made with **Mixtures No. 11 A, B and C,** using about one-half or one-third of the amount used for roses at 15 or 20-day intervals (pp. 648-649).

Carnations.—(1) *Soil* adapted to carnations should pref-

erably be a good clay or sandy loam, one that drains rapidly and has good ventilation. In preparing soil for starting carnation plants out of doors, a pasture with good sod, well drained, is treated with 12 to 15 tons of farm manure and plowed in the fall; it is usually well to apply per acre 1,000 pounds of quicklime after slaking (p. 388). Early in spring the land is plowed again and harrowed until well pulverized and mellow. It is well to add 600 to 800 pounds per acre of a fertilizer like **Mixture No. 8** (p. 603) and, in case of light soils, a liberal coating of well-decomposed farm manure in addition to the fertilizer mixture. When a sod soil of good character is not obtainable, the next best thing is to sow a green-manure crop (p. 348), preferably clover or some other suitable leguminous crop, to be turned under before going to seed. The organic matter thus furnished is thoroughly worked into the soil by plowing and harrowing. The organic matter will decompose more rapidly if treated with 3 or 4 tons of manure just before plowing under (p. 360). In case of light soils, 600 to 800 pounds of **Mixture No. 8** can be used per acre. It is best to use the same type of soil for making compost with manure, using 4 parts of soil to 1 part of well-decomposed manure and preparing just as in case of roses (p. 651) in case the compost is made in spring. If, however, it is made in the fall, one uses 3 parts of loam to 1 part of manure and from 20 to 25 pounds of bone-flour to each cubic yard. When the compost is turned for the first time, one can add 6 to 8 quarts of slaked lime.

(2) *Fertilizers.*—When the plants have been removed to the house, they are not treated with any plant-food until the roots fill the soil. Then they are treated with a manure mulch, as in case of roses. When the days become shorter and colder, one can begin applying liquid manure as with roses. In using plant-food mixtures, follow the directions given under roses. It should be stated

that the carnation is even more sensitive than the rose to overfeeding, especially during cloudy weather or semi-dormant periods, or when roots are not well developed. Excessive accumulation of plant-food in the soil is removed, as in case of roses (p. 651).

Chrysanthemums.—(1) *Soil.*—The best soils for chrysanthemums are such as drain readily and are well venti-

Experiments with chrysanthemums showing methods of cultivation under high feeding. BUREAU OF PLANT INDUSTRY, U. S. DEPT. OF AGR.

lated. To insure this, charcoal and sharp sand are used when needed. In potting, light soil should be very firmly packed, while loose packing answers for heavy soils. As in the case of roses and carnations, the feeding of chrysanthemums involves, first, the compost and, second, the application of plant-foods. The compost is prepared in the same manner as for roses or carnations. Carnation soil should contain plenty of calcium carbonate, but not

more than 7 pounds per cubic yard. The practice of adding nitrate or ammonia nitrogen as a part of composts does not appear to have met with marked success. Such a practice could hardly commend itself, since the conditions in the compost heap would favor denitrification and cause serious loss of nitrogen.

(2) *Fertilizers.*—It is the rule not to give plants any special feeding until the buds begin to appear. The general plan of fertilization is essentially the same as in case of roses. It is believed that a complete fertilizer produces better results than heavy feeding with nitrogen, whether water-extract of manure or nitrogen in the form of nitrate or ammonia. Overfeeding with nitrogen produces in chrysanthemums too great succulence and softness in stems, leaves and petals. Red and other dark varieties are apt to show effects of burning as the result of overfeeding with nitrogen, and with them liquid manure should cease as soon as buds are well formed and of good size. In no case, should liquid manure be used after the flower is about three-quarters expanded. Precautions in feeding chrysanthemums are much the same as in case of the other plants previously considered.

Tomatoes.—(1) *Soil.*—In the case of tomatoes grown in a forcing-house, the character of the soil does not appear to be a matter of as much importance, provided that the drainage be good, as the kind and amount of plant-food used and the method of use. It is believed, however, that best results are produced on a light, sandy loam. A compost made like one used for roses (p. 650) gives satisfaction, especially when bone tankage is added to it at the rate of 100 pounds for 5 cubic yards of compost.

(2) *Fertilizers.*—When good manure is not available, one can work into the soil for 100 square feet 2 pounds of **Mixture No. 8** (p. 603) or **No. 11 A** or **C** (p. 648). When fruit begins to form, one can apply 4 ounces of sodium nitrate in solution one week; 2 pounds of **Mixture No. 8**

the next week can be applied by sprinkling on the soil between the plants and well worked in before watering (p. 650); or, in place of **Mixture No. 8, No. 10 C** can be used, which can be applied in solution by dissolving in 50 gallons of water. Water-extract of manure is sometimes used during the growing period.

Lettuce.—(1) *Soil.*—Lettuce is as sensitive to soil conditions as is the chrysanthemum. Experiment has shown that a mellow light or medium clay loam appears to give

TOMATOES AND BEANS UNDER GLASS. MAINE STATION.

best results. Composts, like those already described, may be used. When a soil is used without composting, it is treated with fertilizer as in case of tomatoes.

(2) *Fertilizers* may be used much the same as for tomatoes. See also p. 632.

NURSERY CROPS

These include young fruit trees and, in addition, ornamental trees, bushes, vines, flowering plants, etc., used largely for out-of-door decorations. The nursery interests of the United States are very extensive and are

located here and there in places where soil and climate combine to furnish the most favorable conditions. The best nursery soils are of the more distinctly clay-loam type, commonly spoken of as "strong" soils. These crops are grown almost, if not entirely, without the use of any plant-food material except farm manure or composts of farm manure with other materials, and sometimes wood-ashes are applied. In many cases, nitrogenous organic matter has been put on to such an extent, in the form of partly decomposed farm manure, that the available phosphorus and potassium furnished by the soil have not been sufficient to produce the kind of normal growth desired. Under these conditions, the growth of leaves and wood is rapid and extreme and is prolonged late in the season, so that the texture of the tree is soft and succulent instead of solid or firm. Such trees easily succumb to injury caused by extremely cold weather and are believed to be more easy of attack by plant diseases. It is highly desirable on every account to keep a liberal amount of organic matter in the soil used for growing nursery stock, but it is also essential that the nitrogen be not applied in amounts that exceed the proper balance between it and the phosphorus and potassium. Therefore, when large amounts (over 20 tons an acre) of farm manure are used, it is desirable to apply some form of phosphorus and potassium. Some growers, without knowing just how the results were brought about, have used wood-ashes to produce firmer stock, but this material is practically unobtainable now at reasonable prices.

It is probable that in most cases where manure has to be purchased and drawn 3 or 4 miles that it is not an economical source of nitrogen or of organic matter. It will be found that the growing of leguminous cover-crops to as great an extent as is practicable can be made to take the place of manure that has to be drawn long distances. The land can be treated, if necessary, with phos-

phorus and potassium compounds in order to secure a good yield of the cover-crops, and comparatively little commercial nitrogen in addition will be called for. The use of cover-crops will also correct the unwise practice of leaving the soil practically bare during the winter.

Nursery crops occupy the ground a few years and are then put into some ordinary farm crop and sooner or later

Feeding and variety experiments with lettuce under glass. Bureau of Plant Industry, U. S. Dept. of Agr.

seeded to grass and used in this way 3 or 4 years before they are again planted with nursery stock. Some make the mistake of depending wholly upon the period intermediate between nursery crops for restocking the soil with organic matter and do not use either farm manure or cover-crops to maintain the supply of organic matter during the growing period of the next nursery crop. The result is that the soil may fail to furnish enough potassium or phosphorus or, even if these are supplied artificially, the lack of organic matter makes the conditions

such that the plants do not utilize them to advantage. When a nursery crop grown under such conditions is removed, it is apt to leave the soil in poor mechanical condition. Clay soil, such as is best adapted for growing nursery products, suffers seriously in its ability to promote the vigorous growth of crops if its supply of organic matter is allowed to diminish too much. In addition, the method of removing a crop of trees is such as to add greatly to impairment of the mechanical condition of the soil. The trees are dug in the fall or early spring when the soil is generally wet and the manipulation of the soil under such conditions by digging and trampling seriously injures the soil structure, causing puddling (p. 96), the effects of which require time and labor to overcome.

Fertilizers.—In considering the need of fertilizers for nursery crops, the question should be first raised as to the character of product that is desired. The chief requisite in a young tree from the nurseryman's standpoint, as well as from that of the orchardist who purchases it, is that it shall be vigorous and hardy; that is, it should be able, when transplanted to its final orchard home, to grow reasonably fast under favorable conditions and to withstand extreme climatic changes to which it is subjected. This result is reached when the physical, chemical and biological conditions of the soil all contribute, along with favorable climatic conditions, to furnish the trees abundance of plant-food at the right time and in sufficient amounts. What these conditions are, was discussed in the first part of this book, and chief among them are good drainage (p. 156), abundance of organic matter (pp. 117-144), a good supply of calcium carbonate (pp. 379-389), good soil structure (p. 101), moisture and abundance of available plant-food. Another feature of producing young trees, desirable from the nurseryman's point of view, is that the growth shall not only be hardy but that it

shall be rapid and continuous, so that the trees shall not occupy the soil longer than necessary. Hardiness and extreme rapidity of growth are not consistent. The aim is, therefore, to hasten growth as rapidly as is consistent with hardiness and vigor. This is done by observing the conditions requisite for growing most crops.

In meeting these needs as applied to nursery crops,

Growing "Granite State" cucumbers in greenhouse for seed. Variety is hybrid produced by crossing English frame cucumber and White Spine. NEW HAMPSHIRE STATION.

we make the following suggestions with reference to the clay soils that are best adapted to the growth of these crops:

(a) Calcium carbonate.—If there are any indications of soil acidity (p. 140), apply once in 4 or 5 years half a ton of quicklime or a ton or more of ground limestone, preferably in connection with the growing of clover or other leguminous crop. Trees use large amounts of calcium in the growth of leaves and wood. The good effects of wood-ashes are due quite as much to the action of the cal-

cium carbonate in the ashes and to the power of wood-ashes to neutralize acidity and modify soil structure as to the nutrient effects of the potassium.

(b) Organic matter and nitrogen can best be furnished by growing clover or some other leguminous crops as a cover-crop between the rows of nursery stock in July or August. Clover can also be grown as one of the rotation-crops during the interim between the removal of one crop and the planting of another. In case there is at any time indication of too much nitrogen in the soil as shown by excessive growth prolonged late into the season, use some non-leguminous crop such as rye or buckwheat for a cover-crop and apply 300 or 400 pounds of acid phosphate or basic-slag phosphate per acre.

(c) Potassium.—On clay soils, such as we have in mind, it will not usually be necessary to supply potassium, provided the soil is limed occasionally and kept supplied with organic matter.

(d.) Phosphorus.—It is probable that in most cases the supply of phosphorus can be amply and most cheaply furnished for both nursery crops and those that follow by incorporating in the soil once in 5 years about 500 to 1,000 pounds of ground phosphate rock (floats), applying it to the soil along with a green-crop manure or with farm manure.

(e) Amounts of plant-food used by nursery crops.—The amounts of nitrogen, potassium and phosphorus required to grow a crop of trees are not large, compared with the requirements of many field crops. Ordinary fruit trees during their growth in the nursery use annually per acre less than 20 pounds of nitrogen, 6 of phosphoric acid (2.6P) and 10 of potash (8.3K).

(f) Effects of nursery crops on soils not due to exhaustion of plant-food.—Nurserymen do not commonly plant one crop of nursery trees after another, because they think that the crop exhausts the soil of those ele-

ments especially needed for that particular kind of crop. When we consider the small amounts of plant-food used by a nursery crop, it is evident that this explanation is inadequate. The real explanation lies largely in the change of mechanical structure of the soil due to frequent cultivation for a prolonged period without maintaining the supply of organic matter, together with the abuse to which the soil is often subjected in removing the trees when the soil is too wet.

(g) Prolonged seasonal growth.—The maximum, but not the most hardy, growth is most easily obtained by furnishing nitrogen in the form of farm manure, in large amounts, which becomes gradually available during the season and which prolongs the growth of foliage and wood beyond the time of season when it should cease, producing a soft growth lacking in hardiness. This is prevented preferably by using smaller amounts of farm manure, but may be corrected by applying phosphorus and potassium compounds.

(h) Light soils.—When nursery stock is grown on light soils, it may be well to apply 200 to 300 pounds of one of the mixures suggested for fruit-crops (p. 676).

(i) Drainage and root growth.—The absolute necessity of good drainage for nursery crops can hardly be emphasized too much. It is essential that a tree, in order to be vigorous, possess a strong root system and no condition is so disastrous to root development as a soil loaded with stagnant water (p. 158).

ORNAMENTAL PLANTS

It is our purpose here to discuss very briefly the general relations of plant-food supply to trees, bushes, vines and other plants grown for ornamental purposes. We shall consider in more detail some special divisions, such as roses, house plants, etc.

Outdoor, hardy, ornamental plants, whether trees or

bushes or vines, are seldom treated with any form of commercial plant-food. When the plants are set, they should be provided with a liberal supply of farm manure thoroughly worked into and mixed with the soil about the roots; this is especially important in case of soils that are poor or not in good mechanical condition. A mulch of well-decomposed manure on the soil about the plant is helpful. In spring, farm manure, or any kind of organic matter obtainable, leaves, straw, etc., is well worked into the surface soil. When trees have become well established, they seldom require any attention even when the soil is only fair in fertility. Bushes and vines will repay annual treatment with a moderate amount of manure or any organic matter, well worked into the surface of the soil. Cultivation or mulching will also be found generally helpful. Bone-meal or tankage can be used to advantage, applying at the rate of a quarter of a pound up, according to size of plant, and working well into the soil for a foot or so around the plant. Hard-wood ashes, made at home, can be used also in this way occasionally.

Roses.—There is probably no flowering plant that gives as much pleasure for the amount of care required as the rose, especially the hardy varieties. They well repay care, especially in the way of liberal feeding. Roses require for best growth, deep, well-drained, mellow loams rich in organic matter, whatever the general character of the soil otherwise, clayey or sandy; soils that are reasonably retentive of moisture are desirable.

In preparing a soil in which rose-bushes are to be set, it should be made deep (15 to 20 inches) and mellow and fine; a very liberal application of farm manure, preferably well-decomposed, if the soil is light, is spread uniformly and worked thoroughly into the soil. After the roots are set and the earth partially filled in around them, put in a generous handful of bone-flour around the plant and then fill in the rest of the earth. When bushes are

set in spring and a rapid early start is desired, one can put in, along with the bone-meal, about a small teaspoonful of pulverized sodium nitrate, and then after the foliage is well started, apply on the surface of the soil around the bush a mixture consisting of one ounce of sodium nitrate and 4 ounces of bone-flour, working lightly into the soil. On light soils, an ounce of potassium chloride can be added to the mixture. Or, in place of such applications, a complete fertilizer can be used like **Mixture No. 4** (p. 562); or any high-grade complete fertilizer such as can be supplied by any fertilizer dealer. When a rose-bush has been established the first season, it can be treated liberally the following spring with manure, which should be well worked into the soil to furnish organic matter, and then liberal applications of nitrate or of a complete fertilizer can be made at intervals during the season. A good plan will be to top-dress with about 1 ounce of nitrate per bush about the time the foliage is well started and then about 4 ounces per bush of **Mixture No. 4** when flower-buds begin to show; another similar application after the first flowering is well along will promote continuance of blossoms through the season. A final application early in August will aid in carrying the plant through the season and enable it to store food supplies that will serve to give it a vigorous start the following season. The large amount of such a plant-food mixture that can be applied without doing harm is surprising to one who has not tested it. It is possible to use such large amounts of fresh farm manure as to promote growth of leaves and branches at the ex

Carl Druschke Roses. (Ellwanger & Barry, Rochester, N. Y.)

pense of flowers; and the same is true of nitrate, if used alone and in large amounts. But if the complete mixture is used after the first spring application of manure and of nitrate, there need be no fear of overgrowth of foliage and branches at the expense of flowers. It must be kept in mind that roses require an abundance of water, and the presence of organic matter in the soil promotes water-holding power.

A liberal dressing of slaked lime or of ground marble or oyster shells, or limestone should be applied once in a few years.

House plants.—It is rare that house plants are given any kind of plant-food, and yet no form of vegetation responds more favorably to feeding. This applies to both flowering and non-flowering plants. Plants grown in boxes for window or veranda decoration can be made to flourish much more vigorously than ordinarily by a little judicious feeding. For the purpose of feeding house plants, one can use either of the following mixtures:

Plant-food mixture for house plants, etc.—

(1) 1½ lbs. of sodium nitrate
1 lb. of dry sodium phosphate, or 3 lbs. of acid phosphate
1 " potassium sulphate

(2) 1 lb. of sodium nitrate
1 " acid phosphate
2 lbs. of bone-flour
1 lb. of potassium sulphate

These will be found as effective as any commercial so-called flower-food, if not much more so, and the ingredients can be purchased and mixed at much less expense than commercial mixtures, which are usually put up in half-pound packages, selling at the rate of $600 a ton and containing plant-food costing about one-tenth of that sum. House-plant Mixture No. 1 is used in the following manner: A rounded tablespoonful is dissolved in 4 quarts of water; warm water can be used if one wishes it to dissolve quickly. About one-fourth of a pint of this solution is used once a week or once in two weeks on a plant

in a 6-inch flower-pot and in corresponding proportions for smaller and larger areas. The solution is poured onto the soil and not on the foliage of the plant. If the mixture of liquid has stood for any length of time, it should always be stirred from the bottom before dipping out to put on the soil. The surface of the soil is kept

WEEPING REED. (ELLWANGER & BARRY, ROCHESTER, N. Y.)

loosened by occasional stirring or, as one would say of field crops, by shallow cultivation. Mixture No. 2, if preferred to No. 1, can be applied in the powdered form at the rate of half a teaspoonful to a 6-inch pot and then carefully mixed into the surface of the soil, for which purpose an ordinary kitchen fork makes a good cultivator.

In connection with the use of plant-food mixtures on house plants, it should be emphasized that this treatment

will not insure good flowers or foliage unless the plants are properly cared for in respect to watering, supply of good air, abundance of sunlight, not too high temperature nor too dry air.

Care of cut flowers.—In connection with the care of house plants, it will not be out of place to say a word about caring for cut flowers so that they will retain their freshness of bloom as long as possible. The writer has found that no single substance is more effective for this purpose than the compound called ammonium nitrate (p. 251, 429). For this purpose one simply puts about one teaspoonful of the powder into one quart of water and places the stems of the flowers in this dilute solution. Cutting off the ends of the stems and renewing the water daily will prolong the keeping-power of flowers for a surprising length of time. If one wishes to make up the solution in large amounts, dissolve one tablespoonful of the powder in 4 quarts of water. In the same way, one can also satisfactorily use a solution of house-plant Mixture No. 1 (p. 666), dissolving at the rate of one tablespoonful in 4 quarts of water.

The data available in regard to the amounts of plant-food constituents used by greenhouse and nursery crops are very meager, as indicated in the following table:

TABLE 63—APPROXIMATE AMOUNTS OF PLANT-FOOD CONSTITUENTS USED ANNUALLY BY NURSERY TREES PER ACRE

Crop	Number per acre	Portion of plant	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
			Lbs.		
Apple trees	8000	Wood	10.0	3.5 (1.5P)	7.0 (5.8K)
Peach "	5000	"	7.5	2.0 (0.9P)	4.0 (3.3K)
Pear "	5000	"	8.0	2.6 (1.1P)	4.5 (3.7K)
Plum "	5000	"	6.5	1.5 (0.7P)	4.0 (3.3K)
Rose bushes	15000	"	13.0	7.0 (3.1P)	12.0 (10. K)
		Leaves	17.0	4.0 (1.8P)	19.0 (16.3K)
		Flowers	3.0	1.0 (0.4P)	4.0 (3.3K)

CHAPTER XXXIV

FRUIT CROPS

We use the word fruit in its popular sense. For our purpose fruits can be conveniently divided into three general classes: (1) Orchard, (2) bush and vine, and (3) strawberries; the two latter classes are commonly called *small fruits*.

SOME GENERAL CHARACTERISTICS OF ORCHARD CROPS

Before we take up the special methods used in furnishing plant-foods to fruit crops, it is important to discuss certain facts of a general character which have a direct bearing on the subject, such as the following: (1) Some differences between orchard and field crops, (2) relations of plant-food constituents to orchard crops, (3) methods of applying fertilizers, (4) relations of soils to orchard crops, (5) tillage of orchards, (6) the use of cover-crops.

Some differences between orchard and field crops.—The study of the plant-food supply of orchards suggests fundamental differences between trees and farm crops such as we have been considering in the chapters preceding. The more prominent points of difference can be briefly stated as follows:

(1) *Preliminary growth.*—Most farm crops begin and end their entire cycle of existence, from seed to seed, in the course of a few months. Trees go through a period of development lasting for several years, during which they merely increase in size and vigor without coming to fruitage.

(2) *Seasonal growth.*—The seasonal growth of most field crops is shorter than that of trees, whose activity begins early in spring, before most field crops have been seeded, and

continues until late in fall after most field crops have been harvested. There is another point of difference in respect to the seasonal growth and that is in the character of it. In field crops, the growth of leaves and stems stops when seed or fruit formation begins, but, in the case of fruit trees, the growth of leaves and wood continues at the same time with the growth of fruit. The growth of one season in fruit trees stores up nutrition in buds and branches, which forms in part the source of supply for the following season.

EXPERIMENTAL PLATS OF SMALL FRUITS. NEW YORK STATE (GENEVA) STATION.

(3) *General character of plant-food.*—When we consider the shorter period in which field crops get their food, we can appreciate the fact that their food-supplies must be in somewhat more concentrated condition and must also be in forms either immediately available or capable of becoming available rapidly enough to meet crop demands during the relatively short period of growth. In the case of trees, comparatively small amounts of plant-food are removed from

the soil in any one season either during the preliminary period of growth or during those not infrequent seasons, when, owing to insects, frosts, drouth, etc., fruit crops fail. And even in the case of bearing fruit-trees, the plant-food requirements are, as a rule, not often more in amount than in case of many field crops giving yields that are really comparable. Therefore, owing to the long-continued feeding season of fruit-trees, it is seen that the plant-food compounds required to supply their needs can be present in the soil solution in smaller amounts and can be in forms that become available more gradually than in the case of field crops. There is another point in this connection that should be mentioned here. In the case of some important field crops, like wheat, barley and other quick-growing crops, the important period of early growth comes when the processes of change in the soil are least active and when quickly available forms of plant-food are apt to be less than at any other time during the year; but, in the case of fruit-trees, there is ample opportunity to benefit by the result of all the biochemical and other changes that occur during the summer months, which contribute to increase the supply of available plant-food.

(4) *Distribution of feeding roots.*—In the case of trees, the roots have a more extended feeding ground than do most field crops, because they go deeper into the soil and at the same time extend laterally in all directions. In relation to the amount of new material actually produced (fruit, leaves and new wood), the root system is in general more extensive in well-grown trees than in the case of most field plants.

(5) *Transpiration of water.*—It is believed that during the growing season more water passes up into trees and out of the leaves than in the case of field crops, when comparison is made on a uniform basis. For this reason, the soil solution carrying plant-food into trees can be more dilute than

in case of field crops and still carry sufficient amounts to furnish nutrition as required.

(6) *Plant-food constituents.*—Fruit crops in general contain a larger percentage of water and, therefore, a smaller percentage of plant-food constituents than most field crops at the same stage of maturity. Speaking of the fruit alone, and not including leaves or new wood, fruit crops use less nitrogen and phosphorus than most field crops, and less potassium than many, when we consider the amounts used per acre by average crops.

(7) *Rotations.*—Field crops and soils get the benefit of properly planned rotations. Orchard crops occupy the ground continuously and represent the single-crop system, except as some superficial variation can be introduced in the way of cover-crops. Orchard crops call year after year for the same kinds of plant-food in about the same relative proportions.

Relations of plant-food constituents to orchard crops. Orchard crops remove nitrogen, phosphorus, potassium and calcium from soils. In this connection we will consider (1) the forms of plant-food materials that can be used, (2) amounts and relative proportions, (3) plant-food mixtures, and (4) the relation of plant-food to quality of fruit.

(1) *Forms of plant-food materials to use*—It has already been pointed out that plant-food constituents can be used by orchard crops when they are in forms so moderately available that they would not meet the needs of quick-growing crops. Therefore, organic nitrogen can be depended upon largely to supply this element; when supplied as a commercial fertilizer, dried blood, cottonseed-meal, fish-scrap, ground tobacco stems, meat-tankage, etc., can be used. However, by the use of appropriate cover-crops it will be easily possible to incorporate into the soil about all of the nitrogen needed. Farm manure should be utilized as far as it is easily obtainable and especially if one does not make a practice of growing cover-crops. Light dressings of farm

manure are very useful. Excessive amounts of nitrogen in proportion to phosphorus and potassium must be avoided, because it makes the fruit ripen more slowly, affects its color, making it greener, and produces new wood of soft texture, lacking in hardiness.

Phosphorus can be furnished partly in the form of acid phosphate and partly in the form of bone-meal or tankage; in many cases the use of basic-slag phosphate has given excellent results, and the application, once in five years, of 500 pounds or more of ground phosphate rock, along with the turning under of a leguminous cover-crop, is well worth trial. It must be remembered that it is useless to apply ground phosphate rock to soils lacking in abundance either of organic matter (p. 117) or of calcium carbonate (p. 369).

Potassium can be applied as high-grade chloride or sulphate, or in the lower-grade form of kainite which has the advantage of containing magnesium compounds. When wood-ashes are obtainable at less than ten dollars a ton, they can be profitably used on soils that are lacking in calcium carbonate as well as potassium.

(2) *Amounts and relative proportions.*—An investigation made by the writer with trees in full vigor of bearing shows that different fruit-trees use per acre in one crop of fruit, foliage and new wood the following amounts of plant-food:

Nitrogen	30 to 75	pounds
Phosphoric acid	7 to 18	"
Potash	33 to 72	"
Calcium oxide (lime)	38 to 114	"

The amount of nitrogen and of potash is about the same in any one kind of tree, while the amount of phosphoric acid is only about one-fourth that of nitrogen or potash. The amounts used by different kinds of trees vary greatly, as shown in the following table:

TABLE 64—AMOUNTS OF PLANT-FOOD USED PER ACRE

Variety	Number of trees per acre	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Magnesia (MgO)
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Apple	35	51.5	14.0	55.0	57.0	23
Peach	120	74.5	18.0	72.0	114.0	35
Pear	120	29.5	7.0	33.0	38.0	11
Plum	120	29.5	8.5	38.0	41.0	13
Quince	240	45.5	15.5	57.0	65.5	19

It is evident that the amounts of plant-food constituents given in this table were present in the soil in available form during the growing season and within reach of the root systems of the trees. If one knew that there were no available plant-food in the soil, the above quantities would be the smallest amounts that one should apply for a season's growth. On the other hand, if one knew how much available plant-food was present in the soil, then it would simply be necessary to supplement this supply, if it were less than the season's requirements. At present we can ascertain what we want to know about the amount of available plant-food the soil can furnish only by rather crude experimenting.

If we consider the relative proportions of plant-food constituents used by different varieties of fruit trees, we find that they are approximately the same for the different kinds studied. This statement is supported by the data embodied in the table following, in which 1 pound of nitrogen is used as a basis of comparison:

TABLE 65—RELATIVE PROPORTIONS OF PLANT-FOOD CONSTITUENTS USED

Variety	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Magnesia (MgO)
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Apple	1	0.27	1.07	1.10	0.45
Peach	1	0.25	0.97	1.53	0.47
Pear	1	0.24	1.10	1.30	0.37
Plum	1	0.29	1.29	1.40	0.52
Quince	1	0.33	1.25	1.44	0.42
Average of all	1	0.27	1.14	1.35	0.45

The results embodied in this table mean that, under like conditions of soil fertility, a mixture of nitrogen, phosphorus and potassium compounds that would meet the requirements of one variety would also meet the needs of other varieties, so far as the supply of these plant-food constituents is concerned. What particular proportions are best adapted to supplement most economically the supply of any particular soil can be determined only by special experiment.

(3) *Plant-food mixtures.*—Taking the various facts at hand into consideration, we suggest some plant-food mixtures as a working basis in fertilizing orchards. Nitrogen from leguminous cover-crops should be depended upon as the main source of supply for this plant-food constituent. We assume that in many soils phosphorus is the constituent most largely needing to be supplemented, though used by fruit trees in relatively small amounts. Potassium is required in relatively large amounts but does not need large applications on most clay soils that are kept well supplied with calcium carbonate and organic matter. On light, sandy soils, potassium can be supplied in larger amounts.

Regarding the special point as to whether fertilizers should be used or not on fruit orchards, it may be offered as a general rule that as long as trees continue to make satisfactory growth of wood and produce average crops of good-colored fruits, no commercial fertilizers need to be supplied. When other conditions prevail, then the fruit-grower should ascertain by specific fertilizer experiments what is needed.

FERTILIZER MIXTURES FOR FRUIT-TREES

A mixture containing 2 per cent. of nitrogen, 5 of phosphoric acid (2.2 P) and 10 of potash (8.3 K) furnishes in 1 ton 40 pounds of nitrogen, 100 of phosphoric acid (44 P) and 200 of potash (165 K). These amounts are furnished approximately in each of the mixtures given below:

Plant-Food Mixtures for Fruits

No. 12 A

400 lbs. cottonseed-meal
400 " bone-meal
100 " acid phosphate
150 " potassium chloride
950 " kainite

No. 12 B

600 lbs. cottonseed-meal
700 " basic-slag phosphate
300 " potassium chloride
400 " kainite

No. 12 C

1000 lbs. tankage (4% nitrogen and 17% phos. acid)
200 " potassium chloride
800 " kainite

No. 12 D

600 lbs. tankage (6½% nitrogen and 9% phos. acid)
300 " acid phosphate
150 " potassium chloride
950 " kainite

No. 12 E

700 lbs. ground tobacco stems
500 " bone-meal
175 " potassium chloride
625 " kainite

No. 12 F

200 lbs. ground tobacco stems
200 " bone-meal
400 " tankage (6½—9)
200 " acid phosphate
200 " potassium chloride
800 " kainite

No. 12 G—*Soluble mixture for use on orchards in sod.*

125 lbs. sodium nitrate
100 " ammonium sulphate
725 " acid phosphate
180 " potassium chloride
870 " kainite

Dried blood is not included because at present prices ($60 a ton), its cost is prohibitive for ordinary use in fertilizers, since organic nitrogen can be obtained much more cheaply in bone-meal, tankage, etc. If for any purpose one desires to increase the percentage of soluble nitrogen, sodium nitrate or ammonium sulphate can be added to any of the mixtures in amounts desired.

Relation of plant-food to quality of fruit.—Under the expression, "quality of fruit," are included such properties as color, flavor, including sweetness and acidity, keeping power, etc. While plant-food constituents unquestionably have more or less influence in determining quality in fruit, we are far from knowing at all fully just what the relations are and still less how to control them. We know that, when

properly fed, fruit-trees produce larger yields of fruit and of higher quality than when underfed. It has been satisfactorily demonstrated that excessive feeding with nitrogen produces fruit of greener color. We know the general relations of nitrogen, phosphorus, potassium, calcium, etc., to many of the physiological processes of plants, but statements are often current of relations which we do not know

FERTILIZER EXPERIMENTS WITH STRAWBERRIES. NEW YORK STATE (GENEVA) STATION.

and which at most represent ingenious guesswork. For illustration, the statement has been made to, and accepted by, many fruit-growers that basic-slag phosphate is of special value in fruit-growing because it contains iron, which exercises an important influence on the coloring of fruit. Whatever some may believe or hope, such statements are without reliable experimental foundation as yet. On a par with this is the custom among some of driving iron nails into fruit-trees or burying iron scraps in contact with the roots.

Another belief that has gained extensive currency is tnat potassium carbonate favors the production of sugar in fruit to a greater extent than sulphate or chloride and that sulphate does so to a greater extent than chloride. The writer carried on extensive experiments for some years with several varieties of fruits to test this question, determining the percentage of sugar and acid at maturity. The results were negative; on the whole, no difference of influence could be found between the different compounds of potassium. If anyone has yet discovered the secret of influencing or controlling important qualities of fruits through regulation of plant-food supplies, he has been successful in keeping the knowledge to himself. Among horticulturists best qualified to discuss the matter, the view seems to be generally held that other conditions, such as sunshine and moisture and temperature, have much more to do with determining the qualities of fruit than the matter of regulation of supply of plant-foods.

Methods of applying fertilizers for fruit-trees.—The method of distributing fertilizers in the soil has an important bearing on the location of the feeding-roots. It is a well-known fact that plant-roots tend to extend themselves most readily in the direction of the most plentiful supply of available plant-food. Top-dressing of orchard soils with fertilizers tends to attract the feeding-roots to the surface; in that location, trees cannot resist drouth as well as when their roots are well down in the soil. Therefore, in order to keep the feeding-roots of trees located in the lower layers of the soil, fertilizers should be worked into the soil as deeply as practicable, and especially when applied during the early growth of trees. Where cultivation is practiced, fertilizers can be distributed on the surface and then plowed in. In the case of orchards in sod, it is better to apply soluble forms of plant-food which are carried down into the soil promptly. For such conditions **Mixture No. 12 G** (p. 676) can be used.

Relations of soils to orchard crops.—An ideal soil for fruit-trees possesses qualities that are common to all soils adapted to raising good crops, such as abundance of plant-food, good physical condition, abundance of organic matter and calcium carbonate and good drainage. Special adaptations for different kinds of orchard trees will be referred to later in connection with each. On soils well suited for orchard crops and properly managed, the application of fertilizers is often not profitable until many years have passed. On soils which are more or less deficient in qualities characteristic of fertile soils, the use of fertilizers will generally be necessary from the start to insure good yield and quality.

Tillage of orchards.—Two systems of soil management have been commonly practiced with fruit orchards, tillage and continuous sod, also called sod-mulch. On hilly and rough lands, tillage is not usually practicable, but the orchards are kept in grass, which is mowed and left to decompose on the ground. Sod treatment formerly prevailed, but cultivation has become very general with all fruits excepting apples. The question in relation to apples has undergone vigorous discussion and is not yet regarded as settled beyond controversy. Experiments carried on for some years by the New York agricultural experiment station in comparing these two methods of orchard management in case of apple orchards have furnished the following results:

(1) *Yield.*—Tillage has annually given 34 bushels more of fruit per acre than sod. Not only is the number of fruits larger, but the average weight of each is greater by 2 ounces in case of tillage as compared with sod.

(2) *Maturity.*—In case of sod, the fruit matures 2 or 3 weeks earlier and has a higher color than in case of tillage. This is due to the effect of maintaining a longer-continued season of growth as a result of keeping up the supply of moisture and of plant-food, particularly the nitrogen.

(3) *Keeping quality.*—Fruit grown on tilled land keeps

longer in common storage than that grown on sod mulch; in cold storage, there is no difference.

(4) *Eating quality.*—Fruit from tilled land is more crisp, juicy and better-flavored than that from sod-mulch.

(5) *Uniformity of trees and yields.*—The growth of trees and yield of crops, both in size and quantity, are more uniform on tilled land.

(6) *Vigor of trees.*—The trees grown on tilled land show more vigor, as indicated (a) by larger gain in diameter of trunk, (b) greater average annual growth in length of branches, and (c) superior leaf development, indicated by size of leaves, amount and weight of foliage, total leaf area and length of time leaves remain on trees, (d) color of leaves, which are of a richer, deeper green on tilled than on sod land.

(7) *Soil moisture.*—Cultivated soils hold water better than those in sod, owing to the transpiration of soil moisture by the growing grass of sod. Thorough tillage begins as early in the spring as is practicable and continues at intervals until July or August.

Use of cover-crops.—An essential part of the system of tillage is the use of cover-crops, which are started in July or August and plowed under the following spring. Cover-crops perform several useful functions (pp. 348-362), but the chief ones are to supply organic matter and also, in case of leguminous crops, organic nitrogen as a source of plant-food supply. Cover-crops are especially needed where farm manure is not obtainable in sufficient amounts.

There is a tendency among some fruit-growers to overlook the value of farm manure in their enthusiasm over leguminous cover-crops, while there are some who neglect both. The manure made on the farm should be utilized as fully as possible, only with the precaution that it should be used as a fairly light dressing instead of in large amounts, especially when applied fresh. The use of manure for the

cover-crops will always be found advantageous; in fact, it may be an absolute necessity in those cases where it is difficult to get cover-crops started. For the general discussion of green-crop manures see pp. 348-362; for treatment of leguminous crops as cover-crops, etc., see pp. 536-556; for other cover-crops, see rye (p. 587), oats (p. 589), buckwheat (p. 594).

In connection with the subject of cover-crops, we will refer briefly to the practice of growing some general farm crop between the rows of fruit-trees during the first years of the life of an orchard before it comes into bearing. Such cropping, often known as *inter-cropping,* permits a certain amount of crop-rotation on the soil and usually calls for the use of commercial fertilizers the same as when the crops are grown by themselves. The following are given as illustrations of rotations practicable for inter-crops:

Strawberries grown under glass on garden soil well fertilized with commercial materials. NEW YORK STATE (GENEVA) STATION.

(a) Potatoes, roots, or market-garden crops, 1 year; corn, 1 year; crimson clover or vetch in fall or spring.

(b) Corn, 1 year; cotton, 1 year; cowpea or velvet bean, 1 year.

(c) Potatoes, 1 year; wheat, 1 year; red-clover, 1 year.

When inter-crops are used, they should be kept far enough from the trees not to permit any interference, one with the other.

In addition to the facts presented in the preceding pages, we need now to consider only some special applications in the case of individual kinds of orchard fruits in so far as these exhibit special characteristics.

Apples can be grown on a great variety of soils but give best results on porous, limestone soils and clay loams.

Fertilizers.—Recent experiments have shown that on fertile soils, especially of heavier types, the use of fertilizers, continued for years even in large amounts, does not show any appreciable effects, whether in case of old orchards or young ones, provided cover-crops, including leguminous, are used and up-to-date methods of tillage practiced. Even applications of nitrogen large enough to be regarded as excessive have not appeared to have any marked influence, favorable or otherwise. However, when the so-called sod-mulch method is used, the application of fertilizers to orchards grown on similar fertile soils gives increased yield of fruit. Under such conditions, it is better to use a fertilizer that is easily soluble, such as that already suggested (**No. 12 G**, p. 676), applying per acre to bearing trees not less than 300 pounds a year and using with it a mixture of 50 pounds of sodium nitrate and 50 pounds of ammonium sulphate, or top-dressing with a light application of farm manure. Such an application will furnish less than one-half the amount of nitrogen used, and about one-half the potassium, while just about adding the needed phosphorus.

On light soils known to be deficient in available plant-food, use of fertilizers should accompany the starting of the orchard and continue regularly. An application of not less than 300 to 600 pounds a year of any of the orchard mixtures (p. 676) is suggested, together with the regular utilization of leguminous cover-crops. On such soils, applications of 1,000 pounds or more of a fertilizer have given profitable returns in case of mature trees in full bearing.

On what might be called good average soils, use of fertilizers may begin when the orchard comes into bearing, applying not less than 300 pounds an acre.

In the case of orchards in which foliage shows lack of color in spring, deficiency of available nitrogen is suggested and calls for a top-dressing of 100 pounds of sodium nitrate.

The question of amounts of plant-food materials to apply must be, as we have repeatedly stated, a matter of individual

experimenting carried on for a series of years. As trees increase in bearing, the amounts of plant-food supplied should be greater.

Pears respond to fertile soils somewhat more noticeably than apples. They are adapted to heavier soils than are apples or peaches, doing best on stiff clay loams or even hard clays that are well drained. They are, however, successfully grown on a great variety of soils, including lighter loams or sandy soils, but the tendency on such soils is to make too rapid growth, producing wood that winter-kills.

Fertilizers.—The statements applying to apples apply also to pears in regard to the use of fertilizers, except that pears do not use such large amounts of plant-food per acre (p.674) and somewhat smaller applications should be sufficient.

Peaches are grown on a great variety of soils from heavy to light, but are best adapted to well-drained, rich, sandy loam. Heavy, compact clay soils are least desirable. Peaches do well even on fairly poor soils. On soils rich in nitrogen, there is danger that growth may be prolonged too far into fall, producing buds and wood that easily winter-kill.

Fertilizers.—Peaches differ from apples and pears in respect to several features which have a bearing upon the matter of plant-food supply: (1) Peach crops are larger consumers of plant-food, compared on the acre basis. Peaches use about one-third more nitrogen, phosphorus and potassium than do apples and twice as much calcium and considerably more magnesium, while they use two to three times as much of each of these constituents as pears do (p. 674). (2) The growing-stage, preliminary to fruit bearing, as well as the life cycle, is shorter with peach-trees. (3) Peach-trees are more sensitive to large nitrogen supply in respect to prolonging growth of foliage and branches late in the season. If nitrate is applied late, or if too large amounts of organic nitrogen are used early, conditions are favorable for prolonging the normal growing season of

leaves and new wood so late that the buds and wood are more easily winter-killed.

For the foregoing reasons, the application of fertilizers to peach orchards should observe the following general rules: (1) Plant-food constituents should be applied in larger amounts than in case of apple or pear-trees under the same soil conditions. (2) The use of nitrogen should be so regulated as to furnish a moderate amount of quickly available nitrogen in spring and enough organic nitrogen to carry the trees through the season without prolonging unduly their growth. The use of leguminous cover-crops must be carefully controlled so as not to overstock the soil with nitrogen. This can be regulated in accordance with the behavior of the trees.

On soils of good average fertility, use 300 to 600 pounds an acre of any one of the orchard mixtures (p. 676) after trees begin fruiting. On poor soils, these amounts may be used when the trees are planted and continued as an annual application. When trees begin bearing, one may use, in addition, 200 to 300 pounds an acre of **Mixture No. 12 G.**

Owing to the fact that peaches are so often grown on poor sandy soils and, therefore, require generous feeding, the impression has become common that the crop must always be heavily fertilized. On good apple soils, peaches require only light feeding in addition to the use of cover-crops and judicious use of farm manure.

Apricots call for the same treatment, in general, as peaches.

Quinces closely resemble apples in their plant-food requirements.

Plums resemble pears more nearly than the other fruits in respect to the amounts of plant-food used.

Cherries do not need heavy applications of fertilizers. An annual application of 300 pounds or more for bearing trees on average soils will meet usual requirements. The crop matures earlier than the other orchard fruits, and to

supply quickly available plant-food one may use equal parts of **Mixture No. 12 G** along with any of the other orchard mixtures. Excessive supply of nitrogen should be avoided.

Citrus fruits include, as the most important representatives, the orange, lemon, grapefruit or pomelo and limes. The same conditions apply essentially to the raising of each of these fruits.

In respect to general methods of management, such as cultivation, use of cover-crops, etc., the general principles developed in connection with other orchard fruits hold good, though special adaptations occur to meet special local conditions. Details of methods practiced in California differ from those of Florida.

Fertilizers.—The quality of citrus fruits is more profoundly affected by the character of the plant-food furnished the trees than in case of our northern fruits. It is stated that excess of nitrogen and especially of organic nitrogen tends to poor quality, such as coarse texture, thick rough skin, and lack of fine flavor, while the use of potassium results in the production of thinner skin, larger proportion of pulp and sweeter juice.

Inorganic materials are more largely used, especially for bearing trees, such as sodium nitrate, ammonium sulphate for nitrogen and acid phosphate for phosphorus; potassium sulphate or the double manure salt (potassium and magnesium sulphate) is used in preference to potassium chloride or to kainite. Organic matter is supplied by means of cover-crops instead of farm manure and care is taken not to allow an excess of nitrogen to accumulate as the result of using leguminous cover-crops too extensively.

During the stage of tree growth preliminary to fruit bearing, such a mixture as the following can be used on light soils: 500 pounds of sodium nitrate, 200 pounds of cottonseed-meal, 500 pounds of acid phosphate and 125 pounds of potassium sulphate. On heavy soils the cottonseed-meal is omitted. The amounts usually applied per tree are as fol-

lows: 1st year, 3 pounds; 2d year, 4½ pounds; 3d year, 6 pounds; 4th year, 9 pounds; 5th year, 12 pounds; 6th year, 15 pounds. It is well to divide the applications, putting on one-half in winter and the rest in summer.

When trees come into bearing, a fertilizer of the following composition, for illustration, can be used:

400 pounds of sodium nitrate,
1,150 pounds of acid phosphate,
450 pounds of potassium sulphate.

The amounts applied are on the basis of the yield of fruit. Thus, for a tree bearing 3 boxes of fruit, 10 pounds of the mixture may be applied; for one bearing 6 boxes, 20 pounds, etc., up to a yield of 10 boxes per tree.

The applications are preferably made in three portions at different times of year as, for example, February, June and September.

The method of application is to broadcast beneath each tree, putting the bulk nearer the center. After distribution, the fertilizer is worked into the soil thoroughly.

SMALL FRUITS

Under this head come grapes, blackberries, raspberries, currants, gooseberries and strawberries as the most important representatives; as a matter of convenience a brief discussion of pineapples is added. These crops possess certain characteristics which resemble those of orchard fruits, but in their general management they are closer to garden crops. Like orchard trees, the plants of small fruits pass through a stage of preliminary growth before they reach the bearing stage, but the length of this period is much shorter than in case of fruit-trees. Unlike fruit-trees, the duration of their bearing life is generally shorter. Grapevines are comparatively long-lived, and gooseberries and currants with proper treatment can be kept in bearing many years, while blackberries and raspberries may continue 8 to

12 years and a strawberry plant does not bear well for more than 2 years. They resemble garden crops in that they are usually subjected to intensive culture and generous feeding. The period of development from the beginning of the season to the fruiting is short in most cases and therefore calls for treatment that takes advantage of this short growing season to get the largest fruitage.

The statements made in connection with orchard fruits with reference to the relations of soils to crops, tillage, use of cover-crops, and inter-crops, apply in modified form to most of the small fruits.

Grapes.—Grapes are widely distributed and the crop is one of the best-bearing of our fruits. The period of preparatory growth before bearing is about 3 years from time of planting of vineyard.

(1) *Soils.*—Grapes grow well on most soils that are well drained and given good cultivation. Soils of quite different character appear equally good; gravelly loams containing considerable clay, open clays, some sandy loams, limestone soils and some others produce most excellent crops.

(2) *Fertilizers.*—Grapes use somewhat larger amounts of plant-food than any of the other small fruits, but not as large as orchard crops. The constituent used in relatively large amounts is potassium. Nitrogen can be largely supplied in the form of leguminous cover-crops. On light soils, one can use per acre 800 to 1,200 pounds of one of the fruit-tree mixtures (p. 676) along with an additional 100 pounds of potassium chloride or sulphate when the vines are in bearing. On soils of good fertility, which have been well managed, one-half the above amounts can be tried. Excessive use of farm manure should be avoided, and generous applications of lime should be made once in four or five years. In Germany and France it is generally believed that the wine-making qualities of grapes are much modified by the methods of feeding.

Blackberries thrive on deep clay loams well supplied

with organic matter, but grow well on a great variety of soils; however, soils that lose moisture too easily just at the time when the fruit is maturing are undesirable.

Fertilizers.—In considering the application of plant-foods, it must be kept in mind that blackberries grow on canes which grew from the roots during the season preceding. The main object of directing the growth is to secure a vigorous development of canes. For this purpose, the less active forms of nitrogen can be used, but should not be applied in such large amounts, relative to phosphorus and potassium, as to prolong the growth of the canes too late to ripen properly, which makes them liable to injury by cold weather. An annual application in spring of 300 to 600 pounds of one of the fruit-tree mixtures (p. 676) will furnish abundance of plant-food in case of good soils. On light soils. additional nitrogen should be provided by leguminous cover-crops. Good results have been obtained by some in applying per acre 75 to 100 pounds of sodium nitrate early in the season after the plants blossom, especially on soils of light character. While this treatment promotes the development of the fruit, the applications should not be such as to produce weak overgrowth of new canes that do not properly mature before the end of the season.

Raspberries.—Deep moist soils well underdrained and supplied with humus furnish best conditions of growth. Red raspberries are better adapted to light loams and black-caps to heavier loams. In respect to the use of fertilizers the statements regarding blackberries apply equally well to raspberries.

Currants grow well on any soil that produces good general farm crops; they do best in a cool climate like that of our northern states. They prefer a cool location and do well in partial shade. When properly cared for in the way of cultivating, feeding and pruning, the bushes continue in bearing for many years.

Fertilizers.—Farm manure was exclusively used for a

long time and the result frequently was an accumulation of nitrogen in the soil, a condition promoting attack by mildew. When farm manure is used, there should be an application of phosphorus and potassium compounds, especially on light soils. The best plan is to provide most of the nitrogen through leguminous cover-crops and use a fertilizer supplying relatively large amounts of phosphorus and potassium. Any of the fruit-crop mixtures (p. 676) will meet these conditions, using from 300 to 600 pounds on heavier soils and larger amounts on light, sandy soils.

Gooseberries are in every respect treated like currants.

Strawberries form the most important of the small-fruit crops, largely because they come as the first fresh fruit of spring. Strawberries grow well on any soil that raises good crops of corn. While clay loams usually produce larger crops, sandy loams ripen their crops earlier. The soil should contain an abundance of organic matter.

Fertilizers.—Strawberry plants have one year of growth preparatory to the fruiting stage. During this preliminary period the chief object is to develop the plant in the highest state of vitality possible and enable it to store in its roots feeding material that will be sufficient to produce a vigorous growth in early spring and so allow it to appropriate plant-food supplies in the soil. Upon the vigor of the plant secured during the preparatory year of growth depends mainly the crop of the following year when the plant comes into bearing. It is obvious, therefore, that the soil in which strawberries are set should contain liberal supplies of readily available plant-food. In the case of soils in good condition, an application of 300 to 500 pounds of **Mixture No. 8** (p. 603) can be used previous to setting out the plants; on poor, light soil more can be used. In the spring following the setting of the plants, an early application of the same fertilizer should be used in the same or larger amounts, put as near the row as practicable and worked into the soil lightly. It is the practice among some growers to apply per acre a

IRRIGATING STRAWBERRIES IN ORCHARD. OREGON STATION.

top-dressing of 100 to 200 pounds of sodium nitrate in the spring after the foliage is well started and before blossoms appear, but in such cases there should be plenty of phosphorus and potassium within reach of the plant. The practice is increasing of applying the complete fertilizer as given above, and then a top-dressing of 100 pounds or more of sodium nitrate about the time of blossoming or immediately after. Large applications of nitrate increase the vigor of the plants and the yield of fruit, provided phosphorus and potassium are also supplied in liberal amounts. Applications of too much nitrogen in relation to phosphorus and potassium usually results in a berry containing a larger percentage of water and softer consistency, impairing its shipping and keeping quality. In applying nitrate, care must be taken to keep it from burning the plants (p. 533).

Pineapples.—The growth of pineapples in the United States is largely confined to a portion of Florida, though crops are grown also in our island possessions, notably in the Hawaiian Islands.

The soil used in Florida is a fine sand containing very small amounts of plant-food. Practically all of the plant-food used by the crop must, therefore, be applied in the form of fertilizers. The annual application per acre of 2,000 to 4,000 pounds of a fertilizer containing 5 per cent. of nitrogen, 4 per cent. of available phosphoric acid and 10 per cent. of potash is practiced. The fertilizer is not all applied at once, but is divided into two to four applications a year; 5 or 6 applications are made during the first 18 months and then 2 a year. It has been found that pineapples are sensitive to certain forms of fertilizing materials which produce injury to growth or to quality or to both. Thus, acid phosphate is not used unless the soil is kept supplied with calcium carbonate, additions of this being made to the soil every year or two at the rate of 1,000 pounds an acre. Sodium nitrate may be used for the first six months, or, with caution, for the first year, but after that only organic

nitrogen is employed, such as dried blood, cottonseed-meal, castor-pomace, tobacco stems or dust, etc. Potassium sulphate, preferably the double manure salt, potassium and magnesium sulphate, is used, and not the chloride and kainite. As soon as possible after the plants are set out, about a tablespoonful of cottonseed-meal, or of a mixture of 3 parts of cottonseed-meal and 1 part of tobacco dust, is dropped

FERTILIZER EXPERIMENTS WITH PINEAPPLES

The soil where plants are large was treated with cottonseed-meal, potassium and magnesium carbonate and bone-meal. The soil where plants are small was treated with cottonseed-meal, kainite and acid phosphate FLORIDA STATION.

into the bud. About 6 weeks later the first regular application of fertilizer mixture is put on broadcast and well worked in. Details vary with different growers, but the following treatment serves as an illustration: In October or early November a mixture of about 700 pounds of blood and bone and 500 pounds of potassium-magnesium sulphate may be

applied, and again the same amount in February. Before the beginning of the rainy season, a third amount is used containing 1,000 to 2,000 pounds of blood and bone and 750 to 1,500 pounds of potash salt.

In the Hawaiian Islands, the conditions of growth are wholly different from those in Florida, only fertile soils being used and the amounts of applied fertilizers being less. An interesting experience in connection with the growing of pineapples in Hawaii shows that, in some of the soils containing manganese oxide in amounts as high as 5 per cent., the young plants start well, but in a few months the leaves turn yellow and many of the plants never bear fruit, or, if any is produced, it is inferior in both size and quality. This trouble is probably caused by the formation of a deposit of manganese oxide about the roots, interfering with their normal functions. On soils containing less manganese, no trouble is experienced.

Typical navel orange grove of Salt River Valley. Irrigated and thoroughly cultivated. ARIZONA STATION.

TABLE 66—APPROXIMATE AMOUNTS OF PLANT-FOOD CONSTITUENTS USED IN ONE CROP

Kind of crop	Yield per acre	Trees per acre	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)
			Lbs.	Lbs.		
APPLE						
Fruit	300 bu	30	6.0	3.0 (1.3P)	15.0 (12.5K)	1.5 (1.1Ca)
Leaves	1000 lbs.	30	10.0	1.5 (0.7P)	3.5 (2.9K)	17.0 (12.1Ca)
New wood ..	100 "	30	0.5	0.2 (0.1P)	0.3 (0.2K)	1.5 (1.1Ca)
Total			16.5	4.7 (2.1P)	18.8 (15.6K)	20.0 (14.3Ca)
PEACH						
Fruit	400 bu.	100	22.2	11.0 (4.8P)	45.5 (37.8K)	2.8 (2. Ca)
Leaves	5300 lbs.	100	47.7	8.0 (3.5P)	42.0 (35. K)	120.8 (86.2Ca)
New wood ..	1500 "	100	8.6	2.0 (0.9P)	2.5 (2. K)	6.4 (4.6Ca)
Total			78.5	21.0 (9.2P)	90.0 (74.8K)	130.0 (92.8Ca)
PEARS						
Fruit	300 bu.	100	7.5	3.0 (1.3P)	15.0 (12.4K)	2.0 (1.4Ca)
Leaves	2400 lbs.	100	16.8	2.9 (1.3P)	9.6 (8. K)	25.0 (18. Ca)
New wood ..	600 "	100	1.8	0.6 (0.2P)	1.5 (1.2K)	4.0 (2.8Ca)
Total			26.1	6.5 (2.9P)	26.1 (21.6K)	31.0 (22.2Ca)
PLUMS						
Fruit	200 bu.	120	15.3	5.5 (2.4P)	21.3 (17.6K)	5.0 (3.6Ca)
Leaves	2000 lbs.	120	15.2	3.5 (1.5P)	16.0 (13.3K)	31.0 (22. Ca)
New wood ..	700 "	120	3.5	1.5 (0.7P)	2.0 (1.6K)	11.5 (8.2Ca)
Total.......			34.0	10.5 (4.6P)	39.3 (32.6K)	47.5 (33.8Ca)
QUINCES						
Fruit	200 bu.	160	12.0	5.5 (2.4P)	25.0 (20.8K)	2.0 (1.4Ca)
Leaves	1500 lbs.	160	13.5	2.7 (1.3P)	6.4 (5.3K)	30.0 (21.4Ca)
New wood ..	400 "	160	2.0	0.8 (0.3P)	1.6 (1.3K)	10.0 (7.2Ca)
Total			27.5	9.0 (4.0P)	33.0 (27.4K)	42.0 (30. Ca)
Cherries	8000 lbs.	120	16.0	4.0 (1.8P)	20.0 (16.6K)	——
Blackberries ..	4000 qts.	—	11.0	3.0 (1.3P)	12.0 (10. K)	——
Red raspber's	4000 "	—	10.5	4.5 (2.0P)	12.0 (10. K)	——
Blackberries ..	3000 "	—	10.0	4.0 (1.8P)	13.0 (10.8K)	——
Strawberries ..	5000 "	—	7.5	3.0 (1.3P)	12.5 (10.4K)	——
Currants	3200 "	—	12.0	5.0 (2.2P)	12.0 (10. K)	——
Gooseberries ..	3200 "	—	6.5	3.0 (1.3P)	12.0 (10. K)	——
Grapes	6000 lbs.	—	9.0	6.0 (2.6P)	18.0 (15. K)	——

P, phosphorus. K, potassium.

CHAPTER XXXV

SPECIAL CROPS: COTTON, TOBACCO, SUGAR-CANE, HOPS, FLAX, PEANUTS

There are some important crops which do not come under any of the groups we have been studying, and which are more or less closely localized; these have been reserved for this closing chapter.

Cotton.—This crop has long been the chief dependence of agriculture in the South, because it is the one from which the farmer obtains most of his income. The cotton-belt of America includes about one-fourth of the area of the United States, extending from Florida and Texas on the south to southern Virginia and northern Oklahoma on the north, though small amounts are grown in scattered spots outside of this area.

All parts of the cotton plant serve some useful purpose. Next to the lint, the seed possesses high value; the oil is widely used in cooking and in manufactures, while the portion remaining after the oil is removed has high value as a fertilizer and as an animal food. The hulls serve as fuel. The roots of the plant furnish a useful drug, while the stems and leaves may be used as fodder or fuel.

Profitable cotton-growing depends on climate, quality of soil, proper soil management and good seed. The cotton crop has been extensively studied by the different experiment stations located in the cotton-belt and a large amount of literature has been published on the methods of growing cotton. The results of this scientific study have raised cotton-growing from a haphazard, soil-exhausting, unprofitable industry to one that can be made to yield satisfactory returns and, at the same time, maintain the soil in a good state of productiveness.

(1) *Crop-rotation for cotton.*—Crop-rotation is, if possible, even more essential to profitable cotton-growing than to that of cereals. Numerous rotations are possible, but a short one of two or three years appears to give best results. The use of a leguminous crop, usually cowpeas, is essential. The following serve as illustrations:

(a) Two years: Oats or corn with cowpeas, 1 year; cotton, 1 year.
Corn and cowpeas, 1 year; cotton and crimson clover, 1 year.
(b) Three " Corn, 1 year; cotton, 1 year, oats with cowpeas or velvet beans, 1 yr.
Corn and cowpeas, 1 year; oats and cowpeas, 1 year, cotton, 1 year.
Cotton and crimson clover, 1 year; corn, 1 year; wheat and cowpeas, 1 year

(2) *Soil and preparation.*—While good crops of cotton can be raised on a great variety of soils, clay loams and silty loams are superior to sandy loams. The best type of soil is a well-drained, light clay loam or medium heavy sandy loam, well provided with organic matter, and with a subsoil not too heavy and compact.

In preparing the soil, the object should be a well-pulverized, loose seed-bed. The cotton plant has a long tap-root which will go well down into the soil if it has a chance. On soils not subject to severe washing, plowing in early winter is practiced, while on lighter soils and those liable to washing, the plowing is done just before planting. Depth of plowing varies from 4 to 8 inches according to the character of the soil. If necessary, the soil is harrowed to make it fine. Two or three weeks before planting, it is laid out in rows varying from 3 to 4 feet wide, leaving a furrow in which fertilizer and seed are placed.

(3) *Fertilizers.*—The use of fertilizers for cotton-growing has been extensively studied and some fairly definite facts have been developed. Conditions are favorable for obtaining plant-food materials to advantage, since leguminous crops supplemented by cottonseed-meal can be used as the chief source of nitrogen, and acid phosphate, produced in the South, is the source of phosphorus.

The only materials that require to be brought from long distances are sodium nitrate, which is used to some extent, and potassium compounds, which are commonly applied either as kainite or chloride. It is stated that the use of kainite is a specific against cotton-rust and blight. On heavy clay soils, little potassium appears to be needed, provided green-crop manures and calcium carbon-

SOUTHERN COTTON-FIELD. SOUTH CAROLINA STATION.

ate are kept in the soil in good supply. Well-decomposed farm manure applied very early in the season gives excellent results, especially when supplemented with 100 to 200 pounds of acid phosphate for each ton of manure. Ground rock-phosphate or "floats" applied with farm manure or with a green-crop manure at the rate of 1,000 pounds an acre once in several years appears to offer promise as a cheap source of gradually available phosphorus, but the effectiveness of this practice has not been sufficiently demonstrated yet.

The cotton crop is far from making heavy drafts on plant-food in soils, and does not require heavy fertilization when only the lint is taken from the farm. The various recommendations indicate an application of 200 to 700 pounds of mixtures containing cottonseed-meal, acid phosphate and potassium chloride. The following are among various mixtures that have been published as suggestions for use in fertilizing cotton:

TABLE 67—PLANT-FOOD MIXTURES FOR COTTON CROPS.

Materials	For clay loam soil	For sandy loam soil with clay subsoil	For sandy soil with clay subsoil	For coarse, sandy soils	For deep, sandy soils
Cottonseed-meal......	750	850	925	900	1000
Acid phosphate.......	1200	1100	1000	1000	875
Potassium chloride ...	50	50	75	100	125

In connection with these mixtures, the suggestion is made that application of sodium nitrate is likely to prove useful, applying as a top-dressing at the rate of 50 to 75 pounds an acre about the middle of May. In some of the states, an application of 100 to 150 pounds of cottonseed-meal and 100 to 200 pounds of acid phosphate, without any potash, is advised; while in others, the following application per acre is used: 120 to 160 pounds of cottonseed-meal, 80 to 120 pounds of acid phosphate and 80 to 120 pounds of kainite.

The method of application commonly followed is distribution in the furrow at the time of planting the seed, while some follow the practice of applying two weeks ahead of planting. Application in the row is more generally advised than broadcasting. One application is preferably made, in general, rather than part at the time of planting and the rest later.

On lands lacking in calcium carbonate, an application

of 1,000 to 2,000 pounds of slaked lime an acre once in 4 or 5 years has proved beneficial.

(4) *Planting and Cultivation.*—In selecting seed, the heaviest is found to give best results. Planting varies from the middle of March to the middle of May, according to locality and season. The rows are 3 to 4 feet apart and the distance between the plants in the rows varies from 12 to 24 inches, being closer on poor soils.

Cultivation commences early and is as frequent as practicable, depending on weather conditions. Cultivation after rains is important,

Tobacco.—The growing of tobacco is a specialty. Not only is the industry localized according to soil or climate or a combination of both, but special varieties are further localized. Moreover, the methods of culture differ widely according to the variety and the purpose for which it is grown. Owing to the complexity of the operations involved, we shall not undertake any discussion of methods of culture but confine our attention to a few facts about soils and rotation in addition to the use of plant-food mixtures.

(1) *Soil.*—Probably no plant is so easily affected by character of soil as tobacco. The variety of tobacco in a particular locality is grown there largely because of the special type of soil found there. The physical properties of the soil appear to be more influential than the chemical. The soil types vary all the way from the coarse, sandy pine barrens to heavy limestone clays.

(2) *Crop-rotations for tobacco.*—The following illustrate rotations practiced in different localities for tobacco growing:

Two years: Tobacco, 1; cowpeas, 1.

Three years: Tobacco, 1; rye or wheat, 1; clover, 1.

Three years: Tobacco, 1; wheat and clover, 1; clover grazed, 1.

Three years: Corn, rye cover-crop, 1; rye plowed under, and tobacco, 1; grass, 1 or 2.

Four years: Clover, 1; corn and cowpeas, 1; tobacco, 1; wheat and clover, 1.

(3) *Fertilizers.*—Tobacco in its relations to plant-food is characterized in two ways: (1st) It uses nitrogen and potassium and calcium in amounts used by few other

FERTILIZER EXPERIMENTS WITH TOBACCO. VIRGINIA STATION.

crops; (2d) its quality is influenced as in the case of few other crops by the kind of plant-food compounds applied. In addition to the fact that the tobacco consumes large amounts of plant-food, the finest qualities are grown only on light, sandy soils, which naturally contain only small amounts of plant-food, and which, for this reason, must be especially heavily fed.

The quality of the crop must be considered as well as the yield, and the application of certain plant-food com-

pounds injures quality. It appears to be generally agreed that presence of the element chlorine in a tobacco fertilizer impairs the quality for smoking. A chloride in a tobacco produces on burning an ash that fuses, and such tobacco is unsatisfactory for smoking on this account, especially in the form of cigars. For this reason, potassium should not be applied in the form of chloride, but only as sulphate or carbonate. Large applications of nitrogen tend to produce thick, heavy leaves, loaded with gummy material, a condition which is desirable in case of manufacturing tobaccos, but unsuitable for those uses which call for thin-textured leaves or fine, bright tobaccos. In respect to the different forms of nitrogen, it is generally believed by investigators that nitrogen in any form is suitable, whether as nitrate, ammonia or organic nitrogen. Plant-food mixtures for tobacco can be made from the usual fertilizing materials, except that compounds or materials containing chloride must be excluded.

The following points should be observed in growing tobacco: (1) The soil should be kept well supplied with calcium carbonate. (2) Organic matter should be kept in the soil in abundance, preferably by means of leguminous crops, which will also furnish much of the nitrogen needed by the tobacco crop. (3) In addition to nitrogen furnished by such crops, nitrogen in any commercial form that is most easily obtainable will answer to furnish the balance needed. In the South, cottonseed-meal is extensively used to advantage. (4) Phosphoric acid is most conveniently furnished in the form of acid phosphate. (5) Potassium should be used only in the form of sulphate or carbonate, and never as chloride. (6) When farm manure is used, it should be well decomposed. (7) Nitrogen, phosphorus and potassium should all be applied, but excessive nitrogenous fertilization avoided.

The following may be regarded as a fair representation of good tobacco fertilizers:

TABLE 68—PLANT-FOOD MIXTURES FOR TOBACCO CROP.

Materials	1	2	3	4
	Lbs.	Lbs.	Lbs.	Lbs.
Sodium nitrate	—	200	200	150
Dried blood	800	600	—	—
Cottonseed-meal	—	—	—	900
Fish-scrap	—	—	800	—
Acid phosphate	800	800	600	600
Potassium sulphate	400	400	400	350

The amount applied of fertilizers of the foregoing composition varies greatly according to conditions of soil and general previous soil management; but the use of 1,000 pounds an acre is commonly regarded as a comparatively light application, while the application of 2,000 pounds is not uncommon.

Sugar-cane.—Most of the sugar-cane in the United States is grown in Louisiana; it is a prominent crop in the island dependencies, forming by far the largest industry in Hawaii, where for many years it has been grown with much intelligent skill.

Sugar-cane requires a warm climate and a fertile soil, well-drained, cultivated and watered. It should be added that the soil must also be well supplied with calcium carbonate. Occasional liming is usually found beneficial. The plowing is generally very deep, 18 inches or more. Good surface cultivation is practiced while the crop is growing, which usually occupies the ground three years or more for each planting, so that frequent crop-rotations are impracticable. It is highly important that between plantings the soil be occupied one year with some other crops, one of which shall be leguminous. One method is to grow a crop of corn and follow it with cowpeas, plowing the leguminous crop under as green-manure. Any of the well-known plant-food materials can be used in fertilizing sugar-cane.

While the crop removes large amounts of plant-food constituents and would therefore impress one as an exhausting crop, it must be remembered that the one substance sold is sugar, a carbohydrate containing no nitrogen, phosphorus, potassium or calcium, except in small traces as impurities. Therefore, practically all of the plant-food material removed can be restored to the soil. This is true of the phosphorus and potassium, but less true of the nitrogen, since much of the extracted cane is used as fuel and the nitrogen thus lost. Experiments indicate that in case of good sugar-cane land in Louisiana, there should be an annual application of nitrogen ranging from 25 to 50 pounds, and about 35 pounds of phosphoric acid (15 P), and potash in accordance with the character of the soil, good clay soils rich in organic matter and calcium carbonate often not requiring any. Commercial fertilizers have been very extensively employed in the growing of sugar-cane and much study has been given to their use. The fertilizer may be applied broadcast and worked into the soil before planting, or it may be placed under the plant-cane and covered with soil at the time of planting. Some apply part of the fertilizer in the row and part later after the plants are well started, distributing it on each side of the row. After a crop has been cut, the stubble cane, when allowed to grow another crop, is not fertilized until about the time each sprout has sent out its own rootlets.

In Hawaii so great variation of soils and rainfall is found that each plantation is apt to have fertilizing problems peculiar to itself. In the districts where excessive rains fall, nitrates are not used much on account of leaching, but organic nitrogen is preferred in forms such as tankage and fish-scrap, while ammonium sulphate can be safely used. Tankage, containing about 8 per cent. of nitrogen and 10 of phosphoric acid (4.4 P), is applied in the furrow at the time of planting and, after the cane is growing well, there is given a top-dressing of a high-grade, easily available fertilizer, especially high in potash, the sulphate being preferred

where the rainfall is heavy, for the reason that it causes less leaching of calcium from the soil than the chloride. In districts where irrigation is practiced, nitrate nitrogen is extensively used. Fertilizers are applied where the irrigation water dissolves and carries the plant-food down to the plant roots.

Hops.—Formerly hop-raising was confined to New York, but it now forms a prominent agricultural industry in the Pacific coast states, Oregon, California and Washington, where it can be carried on under more favorable climatic conditions and cheaper methods. The eastern production has been steadily decreasing for some years.

Rich, sandy loams, moist but not wet, are best suited to hops, but the crop does well on a great variety of soils if well drained.

No extensive systematic studies have been made of the subject of feeding hops, largely for the reason that in the Pacific states fertilizers are not yet used much, while in the East the interest in hop culture has been decreasing. In using plant-food the custom has been to use 12 to 20 tons of farm manure per acre in starting a crop. After the plants are established, a generous forkful of manure is placed on the crown of the plant in the fall, which in the spring is worked into the soil about the plant. Manuring between rows is also practiced. The use of fresh manure in too large amounts is liable to cause excessive growth of leaf and green hops of undesirable quality, as the result of oversupply of available nitrogen. Commercial fertilizers have been successfully used, sometimes in alternation with farm manure. Wood-ashes when more plentiful were extensively used and gave excellent results, especially in combination with ground bone. The most successful practice appears to be that of applying manure on the crown in the fall and then making an application of commercial fertilizers in the spring previous to the first cultivation. Fertilizers having a composition about like those applied to potatoes are com-

monly used for hops. A fertilizer like Mixture No. 9 (p. 603) is well adapted to supply the needs of the hop crop, applying at the rate of 400 to 800 pounds an acre. In case of soils rich in potash, the amount given in this mixture may be reduced one-half.

Flax, while valuable as a fiber crop, is grown in the United States more extensively for its seed, the source of linseed-oil and linseed-meal (p. 254). The principal flax-growing states are Minnesota and the two Dakotas. Flax, when grown for seed, is adapted to about the same climate as wheat, while a cool, moist climate is best suited to the production of the best kind of fiber. Flax has had a bad reputation agriculturally, having long been regarded as a robber and poisoner of all soils with which it comes in contact; but the investigations of some of our experiment stations have proved the falsity of these old errors of belief.

EXPERIMENTS WITH FLAX

Effect of thickness of seeding upon fineness of fiber. No. 1, 1 bu. seed; No. 2, 1¼ bu. seed; No. 3, 2½ bu. seed; No. 4, 1½ bu. seed. Fineness of fiber is largely dependent on thickness of seeding. NORTH DAKOTA STATION.

(1) *Crop-rotation for flax.*—So far as relates to the plant-food relations, traditional rotations for flax, based on the belief that flax should be grown on the same soil only once in several years, have been rejected, and also the simple rotation of small grains and flax has been shown to be wholly undesirable. The prevalence of the flax-wilt disease, the germs of which persist in an infected soil for years, intro-

duces a complication which greatly modifies any rotation based on plant-food requirements. In any rotation system, the elimination of disease germs must be kept in mind. So far as the crop itself is concerned otherwise, the main things to keep in mind are (a) the use of a leguminous crop, usually clover, one or two seasons preceding flax, and (b) such soil management as will insure freedom from weeds. Experimental work on rotations indicates the marked value of one or more crops of cultivated corn in the rotation with the flax crop immediately preceded by hay and pasture for several years.

(2) *Soil and preparation.*—Generally speaking, good corn or wheat soils will grow flax well for seed; moist, deep, clay loams, well drained, are generally better than sandy loams for fiber production. More, however, appears to be dependent on the preparation of the soil than upon the particular type. For a long time it was supposed that the successful growing of flax requires land rich in plant-food constituents and that the crop is a particularly exhausting one. But it has been demonstrated that an average crop of flax uses less total plant-food per acre than a crop of potatoes, corn, wheat, or oats. Another tradition was that soil is badly injured by flax, since it was a common experience that flax could not be successfully grown on the same soil continuously for many years without trouble from what is known as "flax-wilt," a condition ascribed to the soil being "flax-sick." It has been recently shown that this is due to a fungus disease, which is usually introduced into the soil with the seed, and that, therefore, so-called "flax-sickness" is in no sense due to any peculiar character or property of the soil itself. It is, therefore, now generally accepted that the character of the soil is of secondary importance, while the strains of seed used and climatic and seasonal conditions are of more importance.

The aim of soil preparation for the crop should be to furnish a well-worked lower layer such as will give a close

structure for carrying water up to the surface and at the same time so work the surface layer as to provide a fine, mellow but shallow seed-bed about one inch deep. Deep plowing and working should precede seeding time as long as possible in order to make plant-food available for the coming crop.

The two bundles of seed-flax have been bred for resistance to wilt or root-blight fungi. Yield in each case is product of 2 sq. yds. of ground. Bundle 23 (N. D. R. 114 strain) is 12th consecutive crop on flax-sick soil, on which no ordinary flax can live. Bundle 29 (N. D. R. 52 strain) illustrates variation in type or body form obtainable by selection and breeding. NORTH DAKOTA STATION.

(3) *Fertilizers.*—Flax uses twice as much nitrogen as potash and three times as much as phosphoric acid. In feeding flax, the habit of growth should be considered, especially that of the roots, and also the brief period required to complete crop growth. Flax has a delicate, threadlike tap-root with a few slender branches; its tendency is to go down rather than horizontally; the roots have relatively few root-hairs. Its feeding-range is, therefore, much more limited than that of most crops, and it is commonly described as a "dainty feeder." The growing season is very short, most

duces a complication which gre ...n the soil in the first 45
based on plant-food requirem ...sual combination of limited
the elimination of disea' ...d of growth requires that the
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Experimental ...s been shown to work great injury to the
value of one ...ever, such manure is sufficiently decom-
tion with th ...se germs are killed. Large applications of
ture for ...gen are thought to produce too much wood
(2) ... and to thicken the fiber. On light soils, a light
or wh ...ing with nitrogen and potassium at about blossom-
loam ... prolongs the period of growth and is said to result
for ... more pliable, longer straw. Since it has been the custom
er ... in the Northwest to grow flax on virgin soils, the question of
t ... plant-food application has received slight attention. On used
soils nitrogen can be provided, for the most part, by means
of farm manure and leguminous crops used one or two
seasons before flax is grown. Additional nitrogen, if needed, can be provided by a top-dressing of 50 to 75 pounds of sodium nitrate to the growing crop. On soils requiring addition of fertilizer, an application of 200 or 300 pounds of **Mixture No. 4** (p. 562) is suggested. The soil must be kept well supplied with organic matter, especially to hold moisture and keep the soil mellow, in addition to furnishing nitrogen.

(4) *Seeding.*—Strains of seed that are resistant to the attacks of flax-wilt disease are used as far as possible, or else seeds that are carefully treated with some germicide such as formaldehyde. The seed is sown in spring as early as the work can be done without danger of injury to the young plants by frost. The greater amount of growth during the rather cool, rapid-growing months of spring and early summer tends to produce fiber of long and fine type. Prolonged, dry weather hardens the fiber. Uniformity of depth in planting is essential and drilling appears to give best results.

s.—This crop is now grown over quite an ex- including the South Atlantic states and west- .d including California. The uses of the crop are and important, including use as human food, as .-food and plant-food. The plant belongs to the legumi- ous family and is a vigorous gatherer of atmospheric nitrogen. The climatic conditions required are a long season without frost, a comparatively light rainfall during the growing period, plenty of sunshine and warmth.

(1) *Crop-rotation for peanuts.*—Among rotations used in peanut-growing, the following will serve as illustrations:

(a) Two years: Cotton, 1; corn with peanuts, 1.

(b) Two years: Corn with cowpeas or crimson clover, 1; peanuts, 1.

(c) Three years: Cotton, 1; corn, 1; peanuts, 1.

(d) Four years: Corn and cowpeas, 1; peanuts, 1; cotton, 2.

(2) *Soil and preparation.*—The best soil for the peanut crop is a well-drained, sandy loam, fairly well supplied with organic matter and containing an abundance of calcium carbonate. Like most leguminous plants, the peanut crop is sensitive to acidity. When peanuts are grown for market, it is desirable to use soils that are light or grayish in color, rather than dark soils which may stain the shells. When grown for forage or green-manure, larger crops are usually obtained on soils containing considerable clay and retaining water well.

The land is prepared as in case of any other leguminous crop (p. 539); it should be moderately compact, mellow, well pulverized and free from weeds.

(3) *Fertilizers.*—Commercial fertilizers are extensively used in growing the peanut crop. With a good rotation, containing some other leguminous crop, and with the application of farm manure to some other crop in the rotation, little or no nitrogen needs to be used. Mixture No. 2 (p. 543), modified in respect to its constituents, as shown

below, can be used at the rate of 200 to 400 pounds an acre on soils in good condition:

Sodium nitrate......	100 lbs.	(15 lbs. nitrogen)
Cottonseed-meal	350 "	(25 " ")
Acid phosphate	1150 "	(160 " available phosphoric acid, or 70 lbs. P)
Potassium chloride ..	400 "	(200 " potash, or 165 lbs. K)

On soils well provided with nitrogen by farm manure or green-crop manure, a mixture of 250 to 500 pounds an acre may be used, consisting of 1,200 pounds of kainite and 800 pounds of acid phosphate, or 500 pounds of potassium chloride and 1,500 pounds of acid phosphate.

As in the case of other leguminous crops, abundance of calcium carbonate must be kept in the soil. Applications equal to 2,000 to 4,000 pounds of calcium carbonate are usually made once in four or five years (pp. 379-389).

TABLE 69.—APPROXIMATE AMOUNTS OF PLANT-FOOD CONSTITUENTS IN ONE CROP

Crop	Portion of Crop	Yield per acre Pounds	Nitrogen Pounds	Phosphoric Acid (P_2O_5) Pounds	Potash (K_2O) Pounds	Lime (CaO) Pounds
Cotton	Seed...........	550	19.3	7.7 (3.4 P)	6.3 (5.2 K)	1.7 (1.2 Ca)
	Leaves.........	570	12.8	3.3 (1.5 P)	6.3 (5.2 K)	30.3 (21.6 Ca)
	Stems.........	630	4.4	1.3 (0.6 P)	6.3 (5.2 K)	5.0 (3.6 Ca)
	Burrs..........	350	3.5	1.7 (0.7 P)	11.4 (9.5 K)	4.0 (2.9 Ca)
	Lint...........	300	0.6	0.3 (0.1 P)	1.9 (1.5 K)	0.3 (0.2 Ca)
Total		......	40.6	14.3 (6.3 P)	32.2 (26.6 K)	41.3 (29.5 Ca)
Tobacco	Leaves.........	1,000	44.0	5.0 (2.2 P)	57.5 (47.7 K)	55.0 (39.3 Ca)
	Stalks..........	......	15.0	2.7 (1.2)	20.5 (17.0 K)	9.0 (6.4 Ca)
Total		......	59.0	7.7 (3.4 P)	78.0 (64.7 K)	64.0 (45.7 Ca)
Sugar-cane	Stalks, stripped.	30,000	16.2	15.6 (6.9 P)	18.3 (15.2 K)	7.8 (5.6 CaO)
	Leaves and tops	20,000	25.2	7.0 (3.1 P)	18.0 (14.9 K)	27.4 (19.5 CaO)
Total		50,000	41.4	22.6 (10. P)	36.3 (30.1 K)	35.2 (25.1 CaO)
Hops	Cones.........	1,600	27.2	17.6 (7.7 P)	24. (20. K)	....
	Vines and leaves	4,000	26.0	12.0 (5.3 P)	54. (44.8 K)	....
Total		......	53.2	29.6 (13. P)	78. (64.8 K)	....
Flax	Seed...........	900	39.	15. (6.6 P)	19 (15.8 K)	3. (2.1 Ca)
	Straw.........	1,800	15.	3. (1.3 P)	8. (6.6 K)	13 (9.3 Ca)
Total		......	54.	18. (7.9 P)	27. (22.4 K)	16. (11.4 Ca)
Peanuts	Peanuts........	1,500	42.9	8.1 (3.6 P)	6.8 (5.6 K)	1.5 (1.0 Ca)
	Vines and leaves	6,000	25.2	4.2 (1.8 P)	40.0 (33.2 K)	41.4 (29.3 Ca)
Total		......	68.1	12.3 (5.4 P)	46.8 (38.8 K)	42.9 (30.3 Ca)

APPENDIX

APPENDIX

unts of nitrogen, phosphoric acid (P_2O_5), and
commonly present in materials used as sources of
, for those interested in crop growing:

Used as Sources of Nitrogen, Phosphorus and Potassium

Material	Pounds in 100			
	Nitrogen	Phosphoric Acid (P_2O_5)		Potash (K_2O)
		Total	Available	
		13 to 18 (5.7 to 8P)	12 to 16 (5.3 to 7 P)	
	20			
		33 to 44 (15 to 20 P)		
		0.1 to 0.15 (0.04 to 0.07 P)		0.1 to 0.15 (0.08 to 0.12 K)
		0.4 to 0.5 (0.15 to 0 20 P)		0.4 to 0.5 (0.3 to 0.4 K)
		0.5 to 1 (0.2 to 0.4 P)		0.1 to 1.5 (0.08 to 1.2 K)
		1.5 to 2 (0.7 to 0.9 P)		1.5 to 2.5 (1.2 to 2 K)
		1 to 1.5 (0.4 to 0.7 P)		1 to 3 (0.8 to 2.5 K)
		1 to 3 (0.4 to 0.9 P)		4 to 6 (3.3 to 6.6 K)
155)		10 to 18 (4.4 to 8 P)		
	13 to 15			
	6 to 12			
Bone (p. 265 to 271)				
" ash		30 to 35 (13 to 15.5 P)		
" black		25 to 35 (11 to 15.5 P)		
" black, dissolved		13 to 16 (5.7 to 7 P)	12 to 14 (5.3 to 6 P)	
" dissolved	1 to 2	13 to 16 (5.7 to 7 P)	12 to 14 (5.3 to 6 P)	
" meal, steamed	2 to 3	23 to 25 (10 to 11 P)		
" " from glue-making	1 to 1.5	25 to 30 (11 to 13 P)		
" " raw	3 to 4	21 to 25 (9 to 11 P)		
Carnallite (p. 281)				13 to 14 (10.8 to 11.6 K)
Castor-bean pomace (p. 253)	5 to 6	2 to 2.5 (0.9 to 1.1 P)		1 to 1.25 (0.8 to 1 K)
Cottonseed-hull ashes (p. 284)		7 to 12 (3 to 5.3 P)		15 to 25 (12.5 to 20 K)

	7 to 8	2 to 3 (0.9 to 1.3 P)		1.5 to 2 (1.25 to 1.65 K)
	1.32	0.45 (0.20 P)		0.36 (0.30 K)
	8 to 10	5.5 to 7 (2.5 to 3 P)		
	5	3 (1.3 P)		
	7.5 to 9	3 to 6 (1.3 to 2.5 P)		
	11.5	0.8 (0.35 P)		
	3.4 to 3.7	0.10 to 1.47 (0.04 to 0.65)		2.25 to 4.25 (1.8 to 3.5 K)
	0.75	0.20 (0.09 P)		0.4 (0.3 K)
	14 to 16			
)	10 to 15	1.5 to 2 (0.7 to 0.9 P)		
				12 to 13 (10 to 11 K)
	10 to 12			
	7 to 8			
	13 to 14			
chloride).				
te)				
nitrate)				
		36 (16 P)		
		31 (14 P)		
		28 (12 P)		
South Carolina land		27-28 (11 to 12 P)		
Tennessee blue		30 (13 P)		
Ten		32 to 34.5 (14 to 15 P)		
Potassium . 279)				50 to 53 (41.5 to 44 K)
" (p. 281)				61 to 64.5 (50 to 53.5 K)
"				65 to 66.5 (54 to 55 K)
"	13			44 (36.5 K)
" sulphate, 90 to 95 % (p. 280)				48 to 51 (40 to 42 K)
" double manure salt 48 to 53 % (p. 280)				26 to 29 (22 to 24 K)
re salt, 20 %				11 (9 K)
aste	2 to 3			16 to 18 (13 to 15 K)
244)	15 to 16			
Tankage, general range (p. 255)	4 to 10	2 to 18 (1 to 8 P)		
" concentrated	10 to 12	2 to 4 (0.9 to 1.8 P)		
" crushed	4 to 9	3 to 18 (1.3 to 8 P)		
" garbage	1 to 2	0.5 to 1 (0.2 to 0.4 P)		0.5 to 1 (0.4 to 0.8 K)
Thomas slag (see basic slag).				
Tobacco waste (p. 284)	2 to 4	0.5 to 1 (0.2 to 0.4 P)		5 to 10 (4 to 8 K)
Wool waste (p. 260)	5 to 6	2 to 4 (0.9 to 0.18 P)		1 to 3 (0.8 to 2.5 K)

Composition of Farm Manures. See Table 27, page 291.

TABLE 71. AMOUNTS OF NITROGEN, PHOSPHORUS AND POTASSIUM IN FARM PRODUCTS, FEEDING MATERIALS, BY-PRODUCTS, ETC.

	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
Ajax flakes	5.20	0.70 (0.31 P)	0.20 (0.17 K)
Alfalfa, green	0.60	0.15 (0.07 P)	0.50 (0.42 K)
" hay	2.45	0.50 (0.22 P)	2.10 (1.74 K)
Alsike clover (see clover)			
American poultry food	2.20	1.20 (0.53 P)	0.90 (0.75 K)
Animal meal	6.10	....	....
Apple:			
Fruit	0.05	0[illegible] P)	0[illegible]
Leaves	1.00	0[illegible] P)	0[illegible]
New wood	0.50	0[illegible] P)	0[illegible]
Pomace	[illegible]	0[illegible] P)	0[illegible]
Apricot	[illegible]	0[illegible] P)	0[illegible]
Artichoke	[illegible]	0[illegible] P)	0[illegible]
Asparagus, young shoots	[illegible]	0[illegible] P)	0[illegible]
" full-grown plant	[illegible]	0[illegible] P)	0[illegible]
" berries	[illegible]	0[illegible] P)	0[illegible]
Atlas meal, distillery feed	[illegible]	0[illegible] P)	0[illegible]
Balm, fresh stems and leaves	[illegible]	0[illegible] P)	0[illegible]
Barley, bran	[illegible]	0[illegible] P)	0[illegible]
" brewers' grains, dry	[illegible]	1[illegible] P)	0[illegible]
" " " wet	[illegible]	0[illegible] P)	0[illegible]
" chaff	[illegible]	0[illegible] P)	1[illegible]
" feed	[illegible]	1[illegible] P)	0[illegible]
" flour	1.60	0[illegible] P)	0[illegible]
" grain	1.75	0[illegible] P)	0[illegible]
" green forage	0.40	0[illegible] P)	0[illegible]
" ground	1.50	0[illegible] P)	0[illegible]
" malt	1.60	0[illegible] P)	0[illegible]
" malt-sprouts	3.75	1[illegible] P)	1[illegible]
" meal	1.55	0[illegible] P)	0[illegible]
" middlings	2.00	1[illegible] P)	0[illegible]
" straw	[illegible]	0[illegible] P)	1[illegible]
Bean, field, hay	[illegible]	0[illegible] P)	2[illegible]
" " meal	[illegible]	1[illegible] P)	1[illegible]
" " seed	[illegible]	1[illegible] P)	1[illegible]
" " shells	[illegible]	0[illegible] P)	0[illegible]
" " straw	[illegible]	0[illegible] P)	1[illegible]
Beans, garden, beans and pods	[illegible]	0[illegible] P)	0[illegible]
" " leaves	[illegible]	0[illegible] P)	0[illegible]
" " stalks	[illegible]	0[illegible] P)	0[illegible]
Beets, red, roots	[illegible]	0[illegible] P)	0[illegible]
" " tops	[illegible]	0[illegible] P)	0[illegible]
" young roots and tops	[illegible]	0[illegible] P)	0[illegible]
" mangolds or mangels	[illegible]	0[illegible] P)	0[illegible]
" sugar	[illegible]	0[illegible] P)	0[illegible]
" yellow fodder	[illegible]	0[illegible] P)	0[illegible]
Blackberries, fruit	[illegible]	0[illegible] P)	0[illegible]
" leaves	[illegible]	0[illegible] P)	0[illegible]
" new wood	[illegible]	0[illegible] P)	0[illegible]
" old wood	[illegible]	0[illegible] P)	0[illegible]
Brewers' grains (see barley).			
Buckwheat, bran	2.75	1.50 (0.66 P)	1.10 (0.90 K)
" feed	3.00	1.60 (0.70 P)	1.00 (0.80 K)

		UNDS IN 100	
		osphoric id (P_2O_5)	Potash (K_2O)
Cerealine feed	1.70	1. 55 P)	0.65 (0.54 K)
Germ meal	1.80	0. 18 P)	0.20 (0.16 K)
Germ oil meal	3.00	0. 40 P)	0.10 (0.08 K)
Gluten feed, grano	5.00	0. 30 P)	0.20 (0.16 K)
" feed, Queen	3.90	0. 15 P)	trace
" " Star	3.70	0. 15 P)	"
" " Warner's	2.80	0. 13 P)	"
Gluten meal, Buffalo	4.20	1. 51 P)	0.60 (0.50 K)
" " Chicago	5.75	0. 15 P)	trace
" " cream	6.70	0. 13 P)	"
" " globe	4.15	0. 26 P)	0.10 (0.08 K)
" " Hammond	4.50	0. 22 P)	0.10 (0.08 K)
" " Iowa	4.70	0. 20 P)	0.10 (0.08 K)
" " King	6.00	0. 30 P)	0.05 (0.04 K)
" " Nebraska	3.15	0. 20 P)	0.10 (0.08 K)
Hominy feed	1.65	1. 44 P)	0.50 (0.42 K)
" meal	1.75	1. 62 P)	0.75 (0.62 K)
Maizeline	1.60	1. 62 P)	0.80 (0.66 K)
Sprouts	4.15	1. 70 P)	1.85 (1.55 K)
Starch feed, wet	0.80	a	trace
Sugar feed	1.60	0. 09 P)	0.10 (0.08 K)
Corn, sweet, cobs	0.20	0. 04 P)	0.26 (0.22 K)
" " cobs and kernels	0.45	0. 09 P)	0.30 (0.25 K)
" " green fodder	0.30	0. 05 P)	0.30 (0.25 K)
" " husks	0.20	0. 04 P)	0.35 (0.30 K)
" " kernels	0.65	0. 13 P)	0.35 (0.30 K)
" " leaves	0.40	0. 05 P)	0.55 (0.45 K)
" " stalks		0. 03 P)	0.55 (0.45 K)
Cottonseed		1. 55 P)	1.15 (0.95 K)
" feed		0. 20 P)	1.10 (0.90 K)
" hulls		0. 09 P)	1.10 (0.90 K)
" meal		3. 30 P)	1.75 (1.45 K)
Cow-peas, green forage		0. 05 P)	0.45 (0.37 K)
" hay		0. 25 P)	1.75 (1.45 K)
" seed		1. 44 P)	1.20 (1.00 K)
Cream		0. 07 P)	0.13 (0.11 K)
Cucumbers, edible part		0. 03 P)	0.20 (0.17 K)
" leaves		0. 03 P)	0.70 (0.60 K)
" vines		0. 03 P)	0.60 (0.50 K)
Currants, fruit	0.30	0. 05 P)	0.30 (0.25 K)
" leaves	0.70	0. 09 P)	0.95 (0.82 K)
" stems	1.00	0. 15 P)	0.75 (0.62 K)
" new wood	0.45	0. 10 P)	0.35 (0.30 K)
" old wood	0.57	0. 10 P)	0.22 (0.18 K)
Daisy, white, hay	0.25	0. 18 P)	1.20 (1.00 K)
" ox-eye, hay	0.30	0. 20 P)	1.25 (1.05 K)
Dandelion, green	0.35	0. 04 P)	0.60 (0.50 K)
Dewberries	0.22	0. 03 P)	0.20 (0.17 K)
Eggplant, edible part	0.20	0. 02 P)	0.30 (0.25 K)
" leaves	0.85	0. 07 P)	1.00 (0.83 K)
Eggs	2.25	0. 18 P)	0.15 (0.12 K)
Endive	0.30	0. 03 P)	0.75 (0.62 K)
Flax seed	4.35	1. 66 P)	0.95 (0.80 K)
" straw	0.85	0. 09 P)	1.00 (0.83 K)
Fox-grass hay	1.20	0. 09 P)	0.95 (0.80 K)

Germ-meal (see corn pro

Gluten-meal (see corn pr

Material	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
	POUNDS IN 100		
Gooseberries, fruit	0.16	0.08 (0.03 P)	0.03 (0.02 K)
" leaves	0.70	0.23 (0.10 P)	1.13 (0.94 K)
" new wood	0.40	0.21 (0.09 P)	0.40 (0.33 K)
" old wood	0.50	0.25 (0.11 P)	0.40 (0.33 K)
Grape-pomace, fresh	0.95	0.14 (0.06 P)	0.63 (0.52 K)
Grapes, fruit	0.15	0.07 (0.03 P)	0.30 (0.13 K)
" leaves	0.45	0.10 (0.04 P)	0.35 (0.30 K)
" new wood	0.30	0.10 (0.04 P)	0.30 (0.25 K)
Hempseed	2.50	1.75 (0.77 P)	1.00 (0.83 K)
Herd grass	1.00	0.35 (0.15 P)	1.50 (1.25 K)
Hominy feed (see corn products).			
Hops, entire plant, air-dry	1.00	0.60 (0.26 P)	1.40 (1.15 K)
" cones or fruit, dry	1.70	1.10 (0.48 P)	1.50 (1.25 K)
" refuse	1.00	0.20 (0.09 P)	0.10 (0.04 K)
" vines, air dry	0.65	0.30 (0.13 P)	1.35 (1.12 K)
Horehound	0.70	0.15 (0.07 P)	1.00 (0.83 K)
Horse-radish, root	0.40	0.10 (0.04 P)	1.00 (0.83 K)
Hungarian grass, green	0.35	0.15 (0.07 P)	0.50 (0.42 K)
" " hay	1.20	0.40 (0.18 P)	1.40 (1.15 K)
" " seed	1.60	0.45 (0.20 P)	0.40 (0.33 K)
Hyssop	0.50	0.15 (0.07 P)	0.55 (0.46 K)
June grass, hay	1.05	0.35 (0.15 P)	1.45 (1.20 K)
Kentucky blue-grass, hay	1.20	0.40 (0.18 P)	1.55 (1.30 K)
Kohl-rabi	0.50	0.25 (0.11 P)	0.45 (0.37 K)
Lemon culls, Calif.	0.15	0.06 (0.02 P)	0.26 (0.22 K)
Lettuce	0.25	0.08 (0.03 P)	0.45 (0.37 K)
Linseed:			
" meal, old process	5.30	1.75 (0.77 P)	1.30 (1.10 K)
" " new process	5.70	1.85 (0.80 P)	1.40 (1.16 K)
Maize (see corn).			
Malt (see barley).			
Mangolds (see beets).			
Marsh rosemary, hay	0.85	0.05 (0.03 P)	0.25 (0.21 K)
Meadow, fescue, hay	0.95	0.40 (0.18 P)	2.00 (1.65 K)
" foxtail, hay	1.50	0.45 (0.20 P)	0.20 (0.17 K)
" hay, mixed grasses	1.50	0.40 (0.18 P)	1.35 (1.12 K)
Milk	0.50	0.30 (0.13 P)	0.18 (0.15 K)
Millet, common, green	0.30	0.10 (0.04 P)	0.50 (0.42 K)
" " hay	1.25	0.45 (0.20 P)	1.50 (1.25 K)
" " straw	0.70	0.20 (0.09 P)	1.70 (1.40 K)
" " seed	2.00	0.95 (0.42 P)	0.40 (0.33 K)
" barnyard, green	0.25	0.15 (0.07 P)	0.75 (0.63 K)
" " hay	1.30	0.45 (0.20 P)	2.75 (2.30 K)
" Japanese, green	0.30	0.20 (0.09 P)	0.70 (0.58 K)
" " hay	1.10	0.40 (0.18 P)	1.20 (1.00 K)
" " seed	1.60	0.65 (0.54 P)	0.40 (0.33 K)
" pearl, green	0.20	0.15 (0.07 P)	0.45 (0.37 K)
" chaff	0.75	0.20 (0.09 P)	0.45 (0.37 K)
Molasses feed	3.00	0.85 (0.37 P)	2.00 (1.65 K)
Mushrooms	1.10	0.40 (0.18 P)	0.70 (0.58 K)
Muskmelons, fruit	0.22	0.08 (0.03 P)	0.40 (0.33 K)
" vines and leaves	0.35	0.08 (0.03 P)	0.60 (0.50 K)
Oak leaves	0.80	0.35 (0.15 P)	0.15 (0.13 K)
Oat products:			
Canada oat feed	0.70	0.30 (0.13 P)	0.60 (0.50 K)
Cream oat feed	1.15	0.55 (0.24 P)	0.65 (0.54 K)
Friend's oat feed	1.40	0.60 (0.26 P)	0.65 (0.54 K)
Iowa oat feed	1.70	0.50 (0.22 P)	0.55 (0.45 K)

Oat products:			
Monarch oat chop	1.40	0.65 (0	37 K)
Royal oat feed	1.40	0.50 (0	58 K)
Vim oat feed	1.10	0.55 (0	58 K)
"X" oat feed	1.20	0.60 (0	62 K)
Oats and vetch, green fodder	0.30	0.15 (0	25 K)
" " " hay	2.00	0.60 (0	05 K)
Oats, bran	1.35	0.20 (0	58 K)
" chaff	0.75	0.15 (0	37 K)
" chop	1.35	0.65 (0	58 K)
" grain	2.00	0.80 (0	50 K)
" green fodder	0.60	0.15 (0	37 K)
" ground	1.85	0.75 (0	50 K)
" hay	1.50	0.65 (0	80 K)
" hulls	0.55	0.25 (0	42 K)
" middlings	2.40	1.35 (0	90 K)
" straw	0.60	0.20 (0	05 K)
" and peas, green fodder	0.35	0.15 (0	42 K)
" " " hay	1.65	0.60 (0	50 K)
" " " seeds	2.70	1.00 (0	75 K)
" " " straw	0.75	0.40 (0	65 K)
Olives, pomace	1.00	0.14 (0	22 K)
" refuse	1.22	0.18 (0	27 K)
Onions, bulb	0.23	0.09 (0	18 K)
" top	0.30	0.06 (0	45 K)
Oranges, California	0.18	0.05 (0	17 K)
" culls	0.20	0.13 (0	17 K)
" Florida	0.12	0.07 (0	40 K)
Orchard grass, green fodder	0.45	0.15 (0	45 K)
" " hay	1.20	0.35 (0	45 K)
Parsnips, root	0.22	0.20 (0	54 K)
" top	0.42	0.15 (0	08 K)
Pasture grass	0.90	0.25 (0	62 K)
Peaches, fruit pulp	0.08	0.04 (0	17 K)
" stones	0.27	0.07 (0	07 K)
" leaves	0.90	0.15 (0	50 K)
" new wood	0.43	0.10 (0	18 K)
Peanuts, meal cake	7 50	1.30 (0	25 K)
" feed	1.40	0.25 (0	66 K)
" shells	0.80	0.15 (0	42 K)
" meal and shells	1.15	0.15 (0	50 K)
" seeds or kernels	3.60	0.70 (0	37 K)
Pears, fruit	0.05	0.02 (0	08 K)
" leaves	0.70	0.12 (0	33 K)
" wood	0.30	0.10 (0	20 K)
Peas, field, green forage	0.50	0.15 (0	42 K)
" " hay	2.00	0.40 (0	83 K)
" " meal	3.00	0.80 (0	83 K)
" " middlings	3.75	0.65 (0	62 K)
" " seeds	3.75	0.80 (0	83 K)
" " straw	1 40	0.35 (0	83 K)
" garden, green	1.15	0.30 (0	37 K)
" " leaves	0.55	0.07 (0	42 K)
" " pods	0.25	0.05 (0	17 K)
" " vines	0.25	0.05 (0	58 K)
Peppermint, garden	0 35	0.20 (0	54 K)
" wild	0.45	0.17 (0	85 K)
Plums, fruit pulp	0.12	0.05 (0	17 K)

	POUNDS IN 100		
		Phosphoric acid (P_2O_5)	Potash (K_2O)
Skim-milk		0.35 (0.15 P)	0 17 K)
Sorghum, green fodder		0.12 (0.05 P)	0 25 K)
" seed		0.80 (0.35 P)	0 37 K)
Soy beans, green		0.15 (0.07 P)	0 50 K)
" " hay		0.70 (0.31 P)	1 90 K)
" " seed		1.80 (0.80 P)	2 65 K)
" " straw		0.30 (0.13 P)	0 62 K)
Spanish moss		0.10 (0.04 P)	0 46 K)
Sphagnum moss		0.10 (0.04 P)	0 22 K)
Spinach		0.15 (0.07 P)	0 21 K)
Strawberries, fruit		0.06 (0.03 P)	0 21 K)
" hulls	[illegible]	0.09 (0.04 P)	0 33 K)
Street sweepings	0.38	0.40 (0.18 P)	0 25 K)
Sucrene dairy feed	3.10	0.60 (0.26 P)	0 21 K)
Sugar-beet feed, dry	1.30	0.25 (0.11 P)	0 50 K)
" pulp, fresh	0.20	0.30 (0.13 P)	0 08 K)
Sugar beets (see beets).			
Sugar cane	0.20	0.10 (0.04 P)	0.45 (0.37 K)
Sunflower seed	2.25	1.25 (0.55 P)	0.75 (0.62 K)
Sweet clover (see clover).			
Sweet corn (see corn).			
Tall meadow oat grass, hay	1.15	0.	0 K)
Tansy, garden	0.50	0.	2 K)
Tarragon	0.55	0.	2 K)
Teosinte grass	0.35	0.	1 K)
Thyme, French	0.40	0.	5 K)
Timothy, green	0.50	0.	2 K)
" hay	1.25	0.	3 K)
Tobacco, leaves	4.00	0.	0 K)
" stalks	3.70	0.	0 K)
" stems	2.50	0.	0 K)
Tomatoes, fruit	0.20	0.	0 K)
" leaves	0.35	0.	3 K)
" stalks	0.35	0.	2 K)
Turnips, root	0.25	0.	7 K)
" top	0.40	0.	6 K)
" rutabagas	0.20	0.	2 K)
Velvet bean, green	0.55	0.	6 K)
Vetch, hairy, green	0.50	0.	7 K)
" hay	2.80	0.	0 K)
" seed	3.70	1.	1 K)
" straw	1.00	0.	4 K)
" and oats (see oats).			
" kidney, green	0.45	0.10 (0.04 P)	0.30 (0.25 K)
" sand, green	0.55	0.15 (0.07 P)	0.50 (0.42 K)
" spring, green	0.35	0.10 (0.04 P)	0.45 (0.37 K)
Watermelons, fruit	0.17	0.06 (0.03 P)	0.30 (0.25 K)
" vines and leaves	0.50	0.07 (0.03 P)	0.50 (0.42 K)
Wheat, bran	2.65	2.90 (1.28 P)	1.60 (1.33 K)
" chaff	0.75	0.80 (0.35 P)	0.45 (0.37 K)
" feed	2.70	2.00 (0.88 P)	0.55 (0.46 K)
" flour	2.00	0.60 (0.26 P)	0.50 (0.42 K)
" grain	2.00	0.85 (0.37 P)	0.50 (0.42 K)
" middlings	2.50	1.35 (0.60 P)	0.70 (0.58 K)
" shorts	2.80	1.35 (0.60 P)	0.65 (0.54 K)
" straw	0.50	0.15 (0.07 P)	0.60 (0.50 K)
Whey	0.12	0.30 (0.13 P)	0.15 (0.13 K)
Winter savory	0.55	0.20 (0.09 P)	0.70 (0.58 K)
Wormwood	0.70	0.22 (0.10 P)	0.85 (0.70 K)

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